

Model Answers

BIOZONE
Student Workbook

Senior Biology 1

2009



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Senior

Biology 1

Student Workbook



Model Answers: 2009

This model answer booklet is a companion publication to provide answers for the exercises in the **Senior Biology 1 Student Workbook** 2009 edition. These answers have been produced as a separate publication to keep the cost of the workbook itself to a minimum, as well as to prevent easy access to the answers by students. In most cases, simply the answer is given with no working or calculations described. A few, however, have been provided with greater detail because of their more difficult nature.

ISBN 978-1-877462-22-1

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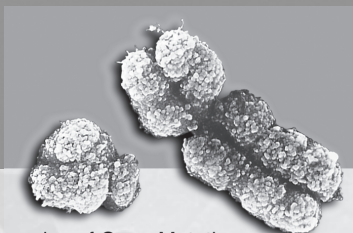
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Hypotheses and Predictions (page 19)

- Prediction: Woodlice are more likely to be found in moist habitats than in dry habitats.
- (a) **Bacterial cultures:**
Prediction: Bacterial strain A will grow more rapidly at 37°C than at room temperature (19°C).
Outline of the investigation: Set up agar plates of bacterial strain A, using the streak plating method. Place 4 plates in a 37°C incubator and 4 on the lab bench. Leave all 8 plates for the same length of time (e.g. 24 hours), with all other conditions identical. Measure the coverage of the agar plates with bacteria (as a percentage).
- (b) **Plant cloning:**
Prediction: A greater concentration of hormone A increases the rate of root growth in plant A.
Outline of the investigation: Set up 6 agar plates infused with increasing concentrations of hormone A (e.g. 1 mg l⁻¹, 5 mg l⁻¹, 10 mg l⁻¹, 50 mg l⁻¹, 100 mg l⁻¹, 500 mg l⁻¹), and each plate with 12 clones of plant A. Measure root length each day for 20 days.

Planning an Investigation (page 21)

- Aim: To investigate the effect of temperature on the rate of catalase activity.
- Hypothesis: The rate of catalase activity is dependent on temperature.
- (a) Independent variable: Temperature.
 (b) Values: 10–60°C in uneven steps: 10°C, 20°C, 30°C, 60°C.
 (c) Unit: °C
 (d) Equipment: A means to maintain the test-tubes at the set temperatures, e.g. water baths; equilibrate all reactants to the required temperatures in each case, before adding enzyme to the reaction tubes.
- (a) Dependent variable: Height of oxygen bubbles.
 (b) Unit: mm
 (c) Equipment: Ruler; place vertically alongside the tube and read off the height (directly facing as you would a meniscus).
- (a) Each temperature represents a treatment.
 (b) No. of tubes at each temperature = 2
 (c) Sample size: for each treatment = 2
 (d) Times the investigation repeated = 3
- It would have been desirable to have had an extra tube with no enzyme to determine whether or not any oxygen was produced in the absence of enzyme.
- Variables that might have been controlled (a–c):
 (a) Catalase from the same batch source and with the same storage history. Likewise for the H₂O₂. Storage and batch history can be determined.
 (b) Equipment of the same type and size (i.e. using test-tubes of the same dimensions, as well as volume). This could be checked before starting.
 (c) Same person doing the measurements of height each time. This should be decided beforehand.
 Note that some variables were controlled: the test-tube volume, and the volume of each reactant. Control of measurement error is probably the most important after these considerations.
- Controlled variables should be monitored carefully to

ensure that the only variable that changes between treatments (apart from the biological response variable) is the independent (manipulated) variable.

Experimental Method (page 23)

- Increasing the sample size is the best way to take account of natural variability. In the example described, this would be increasing the number of plants per treatment. **Note:** Repeating the entire experiment as separate trials (as described) is a compromise, usually necessitated by a lack of equipment and other resources. It is not as good as increasing the sample size in one experiment run at the same time, but it is better than just the single run of a small sample size.
- If all possible variables except the one of interest are kept constant, then you can be more sure that any changes you observe in your experiment (i.e. differences between experimental treatments) are just the result of changes in the variable of interest.
- Only single plants were grown in each pot to exclude the confounding effects of competition between plants (this would occur if plants were grown together).
- Physical layout can affect the outcome of experimental treatments, especially those involving growth responses in plants. For example, the physical conditions might vary considerably with different placements along a lab bench (near the window vs central). Arranging treatments to minimize these effects is desirable.

Checklist to be completed by the student.

Recording Results (page 25)

- See the results table at the top of the next page.
- The table would be three times as big in the vertical dimension; the layout of the top of the table would be unchanged. The increased vertical height of the table would accommodate the different ranges of the independent variable (full light, as in question 1, but also half light, and low light. These ranges would have measured values attached to them (they should be quantified, rather than subjective values).

Variables and Data (page 26)

- Measure wavelength (in nm) using a spectrophotometer; which measures light intensity as a function of the color, or more specifically, the wavelength of light.
- These data are semi-quantitative because an arbitrary numerical value has been assigned to a qualitative scale. The numbers are correct in a relative sense, but do not necessarily indicate the true quantitative values.

Transforming Raw Data (page 27)

- (a) Transforming data involves performing calculations using the raw data to determine such properties as rates, percentages, and totals.
 (b) The purpose of data transformation is to convert raw data into a more useful form.
- (a) **Transformation:** Percentage (percentage cover)

		Trial 1 (CO ₂ conc. in ppm) (day 0)										Trial 2 (CO ₂ conc. in ppm) (day 2)										Trial 3 (CO ₂ conc. in ppm) (day 4)												
		Minutes										Minutes										Minutes												
Set up no.		0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
Full light conditions	1																																	
	2																																	
	3																																	
	Av.																																	

Reason: Abundance alone might not reflect the importance of a species in terms of its dominance in the habitat.

- (b) **Transformation:** Relative value (ml per unit weight)

Reason: this transformation allows animals of different body size to be compared meaningfully without the interfering influence of actual body size.

- (c) **Transformation:** Reciprocal

Reason: Provides a measure of rate where the data have been recorded over very different time periods (time taken for precipitation to occur). It is difficult to compare values where the time scale is different for each recording.

- (d) **Transformation:** Rate

Reason: Data may have been recorded over different time periods. A rate allows the CO₂ production per unit of time to be directly compared over all temperatures (removes the confounding effect of different time periods).

3. Performing data transformations:

- (a) Incidence of cyanogenic clover in different regions:

Clover type	Frost free		Frost prone		Totals
	No.	%	No.	%	
Cyanogenic	124	78	26	18	150
Acyanogenic	35	22	115	82	150
Total	159	100	141	100	300

- (b) Plant transpiration loss:

Time	Pipette arm reading (cm ³)	Plant water loss (cm ³ min ⁻¹)
0	9.0	-
5	8.0	0.2
10	7.2	0.16
15	6.2	0.2
20	4.9	0.26

- (c) Photosynthetic rate at different light intensities:

Light intensity	Average time (min)	Reciprocal of time (min ⁻¹)
100	15	0.067
50	25	0.040
25	50	0.020
11	93	0.011
6	187	0.005

- (d) Frequency of size classes of eels:

Size class (mm)	Frequency	Relative frequency (%)
0-50	7	2.6
50-99	23	8.5
100-149	59	21.9
150-199	98	36.3
200-249	50	18.5
250-299	30	11.1
300-349	3	1.1
Total	270	100.0

Data Presentation (page 29)

- The difference between the two means (labeled A) is not significant, i.e. the two means are not significantly different because the 95% CIs overlap. The mean at 4 gm⁻³ has such a large 95% CI we cannot be confident that it is significantly different from the mean at 3 gm⁻³ with the very small 95% CI.
- Graphs and tables provide different ways of presenting information and each performs a different role. **Tables** summarize raw data, show any data transformations, descriptive statistics, and results of statistical tests. They provide access to an **accurate** record of the data values (raw or calculated), which may not be easily obtained from a graph. **Graphs** present information in a way that makes any trends or relationships in the data apparent. Both are valuable for different reasons. **Note:** Even when you have calculated descriptive statistics for your data and tabulated these for the reader, it is a good idea to include your raw results as an appendix, or at least have them available for scrutiny.

Drawing Bar Graphs (page 30)

1. (a) See table below:

Species	Site 1	Site 2
Ornate limpet	21	30
Radiate limpet	6	34
Limpet sp. A	38	-
Limpet sp. B	57	39
Limpet sp. C	-	2
Catseye	6	2
Topshell	2	4
Chiton	1	3

- (b) Bar graph: See page 4 for graph solutions.

Drawing Histograms (page 31)

1. (a) Tally chart totals as below:

Weight group	Total
45-49.9	1
50-54.9	2
55-59.9	7
60-64.9	13
65-69.9	15
70-74.9	13
75-79.9	11
80-84.9	16
85-89.9	9
90-94.9	5
95-99.9	2
100-104.9	0
105-109.9	1

- (b) Histogram: See next page of graph solutions.

Drawing Pie Graphs (page 32)

1. (a) Tabulated data:

Food item in diet	Ferrets		Rats		Cats	
	% in diet	Angle (°)	% in diet	Angle (°)	% in diet	Angle (°)
Birds	23.6	85	1.4	5	6.9	25
Crickets	15.3	55	23.6	85	-	-
Insects	15.3	55	20.8	75	1.9	7
Voies	9.2	33	-	-	19.4	70
Rabbits	8.3	30	-	-	18.1	65
Rats	6.1	22	-	-	43.1	155
Mice	13.9	50	-	-	10.6	38
Fruits	-	-	40.3	145	-	-
Leaves	-	-	13.9	50	-	-
Unid.	8.3	30	-	-	-	-

- (b) Pie graphs: See next page of graph solutions.

Drawing Kite Graphs (page 33)

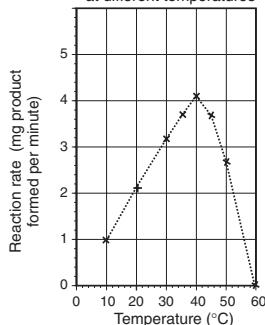
1. (a) Table:

Distance from mouth (km)	Wet weight (g m ⁻²)		
	Stm A	Stm B	Stm C
0	0.4	0.4	0
0.5	0.5	0.6	0.5
1.0	0.4	0.1	0
1.5	0.3	0.5	0.2
2.0	0.3	0.4	-
2.5	0.6	0.3	-
3.0	0.1	-	-
3.5	0.7	-	-
4.0	0.2	-	-
4.5	2.5	-	-
5.0	0.3	-	-

- (b) Kite graph: See next page of graph solutions.

Drawing Line Graphs (page 34)

1. (a) Rate of reaction of enzyme A at different temperatures



- (b) Rate of reaction at 15°C = 1.6 mg product min
- ⁻¹

2. (a) Line graph: See next page of graph solutions.
- (b) The data suggest that the deer population is being controlled by the wolves. Deer numbers increase to a peak when wolf numbers are at their lowest; the deer population then declines (and continues declining) when wolf numbers increase and then peak. **Note:** A scenario of apparent control of the deer population by the wolves is suggested, but not confirmed, by the data. In natural systems, this suggestion (of prey control by a large predator) *may* be specious; most large predators do not control their prey (except perhaps at low population densities in certain systems), but are themselves controlled by the numbers of available prey, which are regulated by other factors such as food availability. In this case, the wolves were introduced for the purpose of controlling deer and were probably doing so. However, an equally valid interpretation of the data could be that the wolves are responding to changes in deer numbers (with the usual lag inherent in population responses), and the deer were already peaking in response to factors about which we have no information.

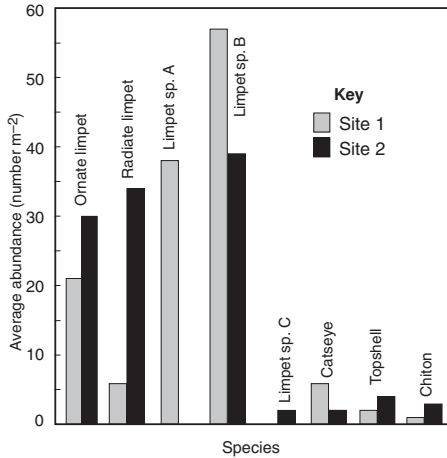
3. (a) Line graph and (b) point at which shags and nests were removed: See the top of page 5.

Interpreting Line Graphs (page 37)

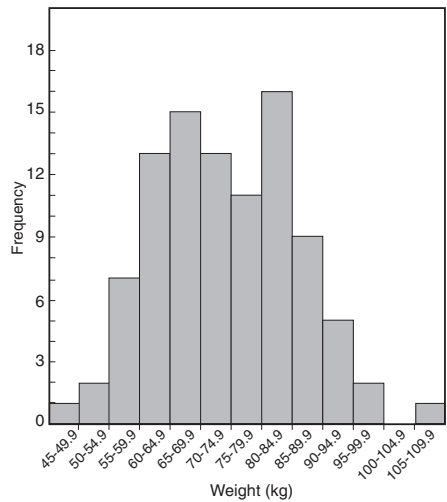
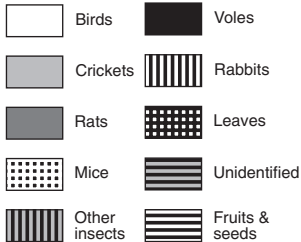
1. (b) **Slope:** Negative linear relationship, with constantly falling slope.
Interpretation: Variable Y decreases steadily with increase in variable X.
- (c) **Slope:** Constant, with slope = 0.
Interpretation: Increase in variable X does not affect variable Y.
- (d) **Slope:** Slope rises and then becomes 0.
Interpretation: Variable Y initially increases with increase in variable X, then levels out (no further increase with increase in variable X).
- (e) **Slope:** Rises, peaks, and then falls (parabolic).
Interpretation: Variable Y initially increases with increase in variable X, peaks and then declines with further increase in variable X.
- (f) **Slope:** Exponentially increasing slope.
Interpretation: As variable X increases, variable Y increases exponentially.

Drawing bar graphs:

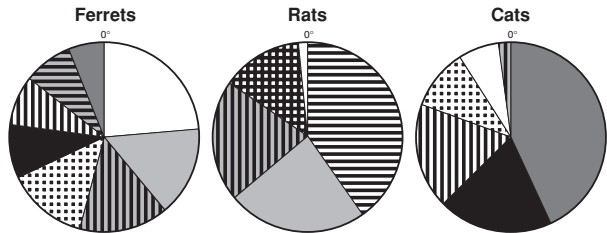
Average abundance of eight mollusc species at two sites along a rocky shore

**Drawing histograms:**

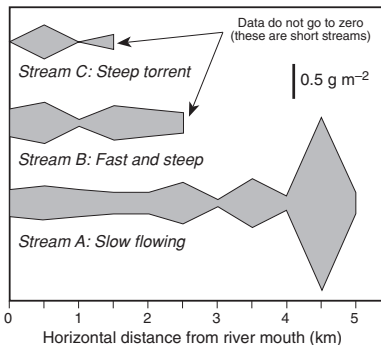
Frequency histogram of weights of 95 individuals (males and females)

**Drawing pie graphs:****Key to food items in the diet**

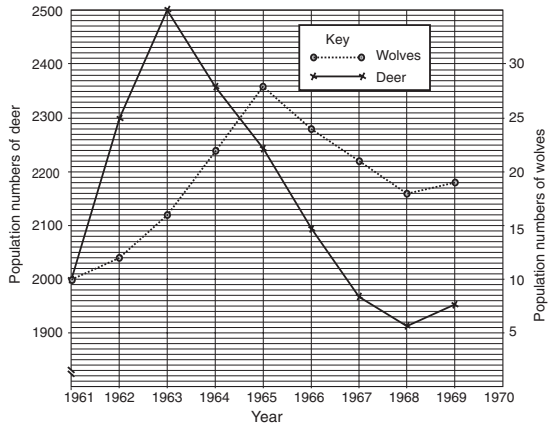
Percentage occurrence of different food items in the diets of ferrets, rats, and cats

**Drawing kite graphs:**

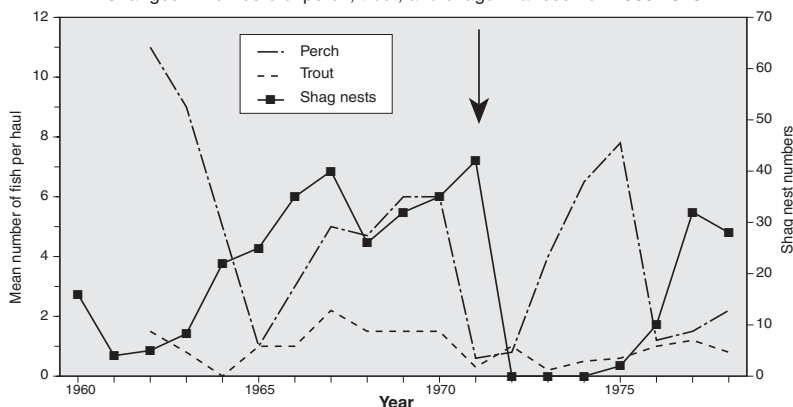
Distribution of invertebrates along 3 different streams as indicated by biomass measured as wet weight (g m⁻²)



Numbers of deer and wolves on an island forest reserve between 1961 and 1969



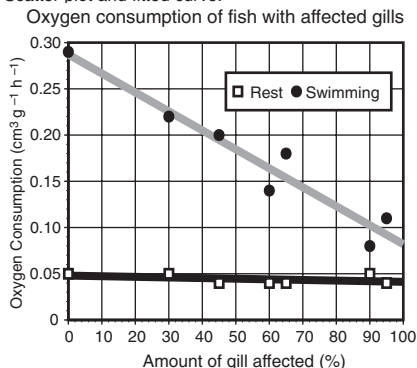
Changes in numbers of perch, trout, and shags in a reservoir 1960-1978



2. (a) Perch population fluctuations follow shag population fluctuations closely.
- (b) The evidence suggests that the fluctuations of shag and trout numbers are not related as the height of trout fluctuations in 1967 is reached before that of shag numbers.

Drawing Scatter Plots (page 38)

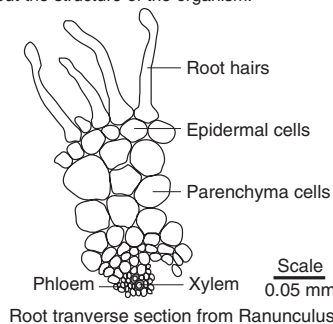
1. Scatter plot and fitted curve:



2. (a) At rest: No clear relationship; the line on the graph appears to have no significant slope (although this could be tested). **Note:** there is a slight tendency for oxygen consumption to fall as more of the gill becomes affected, but the scatter of points precludes making any conclusions about this.
- (b) Swimming: A negative linear relationship; the greater the proportion of affected gill, the lower the oxygen consumption.
3. The gill disease appears to have little or no effect on the oxygen uptake in resting fish.

Biological Drawings (page 39)

1. (a)-(h). Eight of the following, in any order:
 - Lines cross over each other and are angled.
 - Cells are inaccurately drawn: they are not closed shapes, they do not even nearly represent what is actually there; there are overlaps.
 - There is no magnification given.
 - The drawing is cramped at the top corner.
 - Labels are drawn on an angle.
 - There is no indication of whether the section is a cross section or longitudinal section.
 - There is a line to a cell type that has no label
 - Shading is inappropriate and unnecessary; it does not indicate anything.
 - The material being drawn has not been identified accurately in the title by species.
2. Student's response required here. Some desirable features are shown in the figure on the top of the next column, but page position and size cannot be shown.
3. A **biological drawing** is designed to convey useful information about the structure of an organism. From such diagrams another person should be able to clearly identify similar organisms and structures. By contrast, **artistic drawings** exhibit 'artistic license' where the image is a single person's impression of what they saw. It may not be a reliable source of visual information about the structure of the organism.



Descriptive Statistics (page 41)

1. The **modal** value and associated ranked entries indicate that the variable (spores per frond) has a bimodal distribution and the data are not distributed normally. (Therefore) the **mean** and **median** are not accurate indicators of central tendency. Note also that the median differs from the mean; also an indication of a skewed (non-normal) distribution.

2.

Beetle mass (g)	Tally	Total
2.1	I	1
2.2	II	2
2.4	II	2
2.5	IIII	4
2.6	III	3
2.7	I	1
2.8	II	2

Median = 8th value when in rank order
= 2.5

Mode = 2.5

Mean = 2.49
~ 2.5

The Reliability of the Mean (page 45)

Although this is an activity, there is no model answer. Students can follow the steps outlined in the worked example and recreate the figures for themselves. The full spreadsheet analysis of this activity is provided on the Teacher Resource CD-ROM.

The Student's *t* Test (page 47)

- (a) The calculated *t* value is less than the critical value of $t = 2.57$. The null hypothesis cannot be rejected. (There is no difference between the control and the experimental treatments).
(b) The new *t* value supports the alternative hypothesis at $P = 0.05$ (reject the null hypothesis and conclude that there is a difference between the control and experimental treatments). Note the critical value of *t* in this case is 2.23 at 10 d.f. $P = 0.05$.
- Outliers can skew the data set, leading to mean values between data sets that are very different (even though the bulk of the data may not be very different). This could result in the rejection of H_0 when it is true.
- Statistical significance refers to the probability that an observed difference (or trend) will occur by chance. It is an arbitrary criterion used as the basis for accepting or rejecting the null hypothesis in an investigation. **Note:** in science the term 'significantly different' has a specific meaning and should not be used in a casual manner when no statistical test has been performed.

The Structure of a Report (page 48)

- (b) **Methods:** provides the reader with instructions on how the investigation was carried out and what equipment was used. Allows for the procedures to be repeated and confirmed by other investigators.
- (c) **Results:** Provides the findings of the investigation and allows the reader to evaluate these themselves.
- (d) **Discussion:** The findings of the work are discussed in detail so the reader can evaluate the findings. Design limitations, and ways the work could have

been improved are also presented.

- (e) **References/Acknowledgments:** Lists sources of information and help used during the investigation. The reader can review the references for more detail if required, and compare your work with other studies in the area of investigation.

2. A poster presents all of the key information from an investigation in an attractive, concise manner which is readily accessible and easy to read. People can quickly determine if the study is of interest to them, and the references provide an opportunity to find out further information if required.

Writing the Methods (page 49)

- (a)-(h) Any of the following in any order:
 - Number of worms used not stated.
 - No description of the pond (size, water depth etc.).
 - Value of "room" temperature not stated.
 - Date somewhat irrelevant (time of year could be).
 - Source of seawater not stated.
 - Conditions of the worms before the experiment was not stated.
 - Volume of 100% seawater used not stated.
 - Dilution of seawater not stated.
 - Volume of diluted seawater used not stated.
 - Weighing equipment used not stated.
 - Time interval for reweighing not stated.

Writing Your Results (page 50)

- Referring to tables and figures in the text clearly indicates which data you are referring to in your synopsis of the results and gives the reader access to these data so that they can assess your interpretation.
- Tables summarize data and provide a record of the data values, which may not be easily obtained from a graph. Graphs present information in a way that makes any trends or relationships in the data apparent. Such trends may not be evident from the tabulated data. Both formats are valuable for different reasons.

Writing Your Discussion (page 51)

- Discussion of weaknesses in your study shows that you have considered these and acknowledged them and the effect that they may have had on the outcome of your investigation. It also provides the opportunity for those repeating the investigation (including yourself) to improve on aspects of the design.
- A critical evaluation shows that you have examined your results carefully in light of the question(s) you asked and your predictions. Objective evaluation enables you to provide reasonable explanations for any unexpected or conflicting results and identify ways in which to improve your study design in future investigations.
- The conclusion allows you to make a clear statement about your findings, i.e. whether or not the results support your hypothesis. If your results and discussion have been convincing, the reader should be in agreement with the conclusion you make.

Report Checklist (page 52)

To be completed by the student.

Citing and Listing References (page 53)

1. A bibliography lists all sources of information whereas a reference list includes only those sources that are cited in the text. Usually a bibliography is used to compile the final reference list, which appears in the report.
2. Internet articles can be updated as new information becomes available and the original account is revised. It is important that this is noted because people using that source in the future may find information that was unavailable to the author making the original citation.
3. Reference list as follows:
 Ball, P. (1996): Living factories. *New Scientist*, 2015, 28-31
 Campbell, N. (1993): *Biology*. Benjamin/Cummings. Ca.
 Cooper, G. (1997): *The cell: a molecular approach*. ASM Press, Washington DC. pp. 75-85
 Moore, P. (1996): Fuelled for Life. *New Scientist*, 2012, 1-4
 O'Hare, L. & O'Hare, K. (1996): Food biotechnology. *Biological Sciences Review*, 8(3), 25.
 Roberts, I. & Taylor, S. (1996): Development of a procedure for purification of a recombinant therapeutic protein. *Australasian Biotechnology*, 6(2), 93-99.

The Biochemical Nature of the Cell (page 57)

1. (a) Low viscosity: Water flows through very small spaces and capillaries. It also enables aquatic organisms to move through it without expending a lot of energy.
 (b) Colorless and transparent: Light penetrates tissue and aquatic environments. This property allows photosynthesis to continue at considerable depth.
 (c) Universal solvent: It is the medium for the chemical reactions of life. Water is also the main transport medium in organisms.
 (d) Ice is less dense than water: Ice floats and also insulates the underlying water.
2. (a) Lipids are important as a ready store of concentrated energy (their energy yield per gram is twice that of carbohydrates). They also provide insulation and a medium in which to transport fat-soluble vitamins. Phospholipids are a major component of cellular membranes.
 (b) Carbohydrates are a major component of most plant cells, a ready source of energy, and they are involved in cellular recognition. They can also be changed into fats.
 (c) Proteins are required for growth and repair of cells. They may be structural, catalytic, or have a variety of other functions as well as being able to be converted into fats.
 (d) Nucleic acids, e.g. DNA and RNA, encode the genetic information for the construction and functioning of an organism.

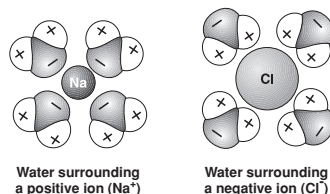
Organic Molecules (page 58)

1. Carbon, hydrogen, and oxygen.
2. Sulfur and nitrogen.

3. Four covalent bonds (valency of 4).
4. A molecular (or chemical) formula shows the numbers and kinds of atoms in a molecule whereas a structural formula is the graphical representation of the molecular structure showing how the atoms are arranged.
5. A functional group is an atom or group of atoms, such as a carboxyl group, that replaces hydrogen in an organic compound and that defines the structure of a family of compounds and determines the properties of the family.
6. It is an aldehyde.
7. Either one of: amine group (NH_2) or carboxyl group (COOH).
8. The amino acid cysteine has an R group (SH) that can form disulfide bridges with other cysteines to create cross linkages in a polypeptide chain (protein).

Water and Inorganic Ions (page 59)

1.



2. The **dipole nature** of water means that it is a good solvent for many substances, e.g. ionic solids and other polar molecules such as sugars and amino acids. It is therefore readily involved in biochemical reactions.
3. Inorganic compounds can be formally defined with reference to what they are not, i.e. organic compounds. Organic compounds are those which contain carbon, with the exception of a few types of carbon containing inorganic compounds such as carbonates, carbon oxides, and cyanides, as well as elemental carbon.
4. (a) Calcium: Calcium ions (Ca^{2+}) are a component of bones and teeth. Ca^{2+} also functions as a biological messenger.
Deficiency: Depletion of bone stores and increased tendency to bone fracture, disturbance to calcium regulating mechanisms, impairment of nerve and muscle function.
 (b) Iron: Iron ions (Fe^{2+}) are a component of hemoglobin, the main oxygen carrying molecule, where Fe^{2+} is the central ion of the molecule.
Deficiency: Anemia, fatigue, pallor, irritability, general weakness and breathlessness.
 (c) Phosphorus: Phosphate ions (PO_4^{3-}) are a component of adenosine triphosphate (ATP), an energy-currency molecule which stores energy in an accessible form. Bone is calcium phosphate.
Deficiency: Anorexia, impaired growth, skeletal demineralization, muscle atrophy and weakness, cardiac arrhythmia, respiratory insufficiency, decreased blood function, nervous system disorders, and even death.
 (d) Sodium: Sodium ions (Na^+) have a role similar to

potassium ions in the sodium-potassium pump.
Deficiency: Electrolyte disturbances and water intoxication (toxic water levels in the blood).

- (e) Sulfur: As part of four amino acids, sulfur is important in a number of the redox reactions of respiration, in carbohydrate metabolism, in protein synthesis, liver function, and in blood clotting. Hydrogen sulfide (H_2S) replaces H_2O in photosynthesis of some bacteria.
Deficiency: Rare, but sulfur deficiency is attributed to circulatory problems, skin disorders, and various muscle and skeletal dysfunctions.
- (f) Nitrogen: Nitrogen is a constituent element of all living tissues and amino acids.
Deficiency: Notable in plants with stunting of growth and yellowing of leaves. In animals, nitrogen deficiency manifests as various types of protein deficiency disease, e.g. kwashiorkor, which is characterized by degeneration of the liver, severe anemia, edema, and inflammation of the skin.

Biochemical Tests (page 60)

- $R_f = 15 \text{ mm} \div 33 \text{ mm} = 0.45$
- R_f must always be less than one because the substance cannot move further than the solvent front.
- Chromatography would be an appropriate technique if the sample was very small or when the substance of interest contains a mixture of several different compounds and neither is predominant.
- Immersion would just wash out the substance into solution instead of separating the components out behind a solvent front.
- Leucine, arginine, alanine, glycine (most soluble to least soluble).
- Lipids are insoluble in water. They will not form an emulsion in water unless they have first been dissolved in ethanol (a non-polar solvent).

Carbohydrates (page 61)

- Structural** isomers have the same molecular formula but their atoms are linked in different sequences. For example, fructose and glucose are structural isomers because, although they have the same molecular formula ($C_6H_{12}O_6$), glucose contains an aldehyde group (it is an aldose) and fructose contains a keto group (it is a ketose). In contrast, **optical** isomers are identical in every way except that they are mirror images of each other. The two ring forms of glucose, α and β glucose, are optical isomers, being two mirror image forms.
- Isomers will have different bonding properties and will form different disaccharides and macromolecules depending on the isomer involved, e.g. glucose and fructose are structural isomers; glucose + glucose forms maltose, glucose + fructose from sucrose. A polysaccharide of the α isomer of glucose forms starch whereas the β isomer forms cellulose.
- Compound sugars are formed and broken down by condensation and hydrolysis reactions respectively. Condensation reactions join two carbohydrate molecules by a glycosidic bond with the release of a water molecule. Hydrolysis reactions use water to split

a carbohydrate molecule into two, where the water molecule is used to provide a hydrogen atom and a hydroxyl group.

- Cellulose, starch, and glycogen are all polymers of glucose, but differ in form and function because of the optical isomer involved, the length of the polymers, and the degree of branching. **Cellulose** is an unbranched, long chain glucose polymer held by β -1,4 glycosidic bonds. The straight, tightly packed chains give cellulose high tensile strength and resistance to hydrolysis. **Starch** is a mixture of two polysaccharides: amylose (unbranched with α -1,4 glycosidic bonds) and amylopectin (branched with α -1,6 glycosidic bonds). The α -1,4 glycosidic bonds and more branched nature of starch account for its physical properties; starch is powdery and more easily hydrolyzed than cellulose, which exists as tough microfibrils. **Glycogen**, like starch, is a branched polymer. It is similar to amylopectin, being composed of α -glucose molecules, but it is larger and more there are more α -1,6 links. This makes it highly branched, more soluble, and more easily hydrolyzed than starch.

Lipids (page 63)

- In phospholipids, one of the fatty acids is replaced with a phosphate; the molecule is ionized and the phosphate end is water soluble. Triglycerides are non-polar and not soluble in water.
- (a) Solid fats: Saturated fatty acids.
 (b) Oils: Unsaturated fatty acids.
- The amphipathic nature of phospholipids (with a polar, hydrophilic end and a hydrophobic, fatty acid end) causes them to orientate in aqueous solutions so that the hydrophobic 'tails' point in together. Hence the bilayer nature of phospholipid membranes.
- (a) Saturated fatty acids contain the maximum number of hydrogen atoms, whereas unsaturated fatty acids contain some double-bonded carbon atoms.
 (b) Saturated fatty acids tend to produce lipids that are solid at room temperature, whereas lipids that contain a high proportion of unsaturated fatty acids tend to be liquid at room temperature.
 (c) The cellular membranes of an Arctic fish could be expected to contain a higher proportion of unsaturated fatty acids than those of a tropical fish species. This would help them to remain fluid at low temperatures.
- (a) and (b) any of the following:
 - Male and female sex hormones (testosterone, progesterone, estrogen): regulate reproductive physiology and sexual development.
 - Cortisol: glucocorticoid required for normal carbohydrate metabolism and response to stress.
 - Aldosterone: acts on the kidney to regulate salt (sodium and potassium) balance.
 - Cholesterol is a steroid lipid and, while not a steroid itself, it is a precursor to several steroid hormones and a component of membranes.
- (a) Energy: Fats provide a compact, easily stored source of energy. Energy yield per gram on oxidation is twice that of carbohydrate.
 (b) Water: Metabolism of lipids releases water (**Note:**

Oxidation of triglycerides releases twice as much water as carbohydrate).

- (c) **Insulation:** Heat does not dissipate easily through fat therefore thick fat insulates against heat loss.

Amino Acids (page 65)

1. Amino acids are the building blocks for constructing proteins (which have diverse structural and metabolic functions). They may also be important (directly or as precursors) as intermediates in metabolic reactions, or neurotransmitters and hormones.
2. The side chains (R groups) differ in their chemical structure (and therefore their chemical effect). Different R groups confer properties such as acidity (acidic amino acids) or alkalinity (basic amino acids). These properties are important when amino acids are in proteins, because they play a role in preventing pH changes in cells and organisms.
3. Translation of the genetic code. Genetic instructions from the chromosomes (genes on the DNA) determine the order in which amino acids are joined together.
4. Essential amino acids cannot be manufactured by the human body, they must be included in the food we eat.
5. Condensation reactions involve the joining of two amino acids (or an amino acid to a dipeptide or polypeptide) by a peptide bond with the release of a water molecule.
6. Hydrolysis involves the splitting of a dipeptide (or the splitting of an amino acid from a polypeptide) where the peptide bond is broken and a water molecule is used to provide a hydrogen atom and a hydroxyl group.
7. The L-form.

Proteins (page 67)

1. (a) **Structural:** Proteins form an important component of connective tissues and epidermal structures: collagen, keratin (hair, horn etc.). Proteins are also found scattered on, in, and through cell membranes, but tend to have a regulatory role in this instance. Proteins are also important in maintaining a tightly coiled structure in a condensed chromosome.
- (b) **Regulatory: Hormones** such as insulin, adrenaline (modified amino acid), glucagon (peptide) are chemical messengers released from glands to trigger a response in a target tissue. They help maintain homeostasis. **Enzymes** regulate metabolic processes in cells.
- (c) **Contractile:** Actin and myosin are structural components of muscle fibers. Using a ratchet system, these two proteins move past each other when energy is supplied.
- (d) **Immunological:** Gamma globulins are blood proteins that act as antibodies, targeting antigens (foreign substances and microbes) for immobilization and destruction.
- (e) **Transport:** Hemoglobin and myoglobin are proteins that act as carrier molecules for transporting oxygen in the bloodstream of vertebrates. Invertebrates usually have some other type of oxygen carrying molecule in the blood.
- (f) **Catalytic:** Enzymes, e.g. amylase, lipase, lactase, trypsin, are involved in the chemical digestion of

food. A vast variety of other enzymes are involved in just about every metabolic process in organisms.

2. Denaturation destroys protein function because it involves an irreversible change in the precise tertiary or quaternary structure that confers biological activity. For example, a denatured enzyme protein may not have its reactive sites properly aligned, and will be prevented from attracting the substrate molecule.
3. Any of the following:
 - Globular proteins have a tertiary structure that produces a globular or spherical shape. Fibrous proteins have a tertiary structure that produces long chains or sheets, often with many cross-linkages.
 - The structure of fibrous proteins makes them insoluble in water. The spherical nature of globular proteins makes them water soluble.
4. (a) 21 amino acids (b) 29 amino acids

Enzymes (page 69)

1. Catalysts cause reactions to occur more readily. Enzymes are biological molecules (usually proteins) and allow reactions that would not otherwise take place to proceed, or they speed up a reaction that takes place only slowly. Hence the term, **biological catalyst**. The **active site** is critical to this function, as it is the region where substrate molecules are drawn in and positioned in such a way as to promote the reaction.
2. **Catabolism** involves metabolic reactions that break large molecules into smaller ones, e.g. digestion and cellular respiration. They release energy and are therefore **exergonic**. In contrast, **anabolism** involves metabolic reactions that build larger molecules from smaller ones, e.g. protein synthesis and photosynthesis. They require the input of energy and are **endergonic**.
3. The lock and key model proposed that the substrate was simply drawn into a closely matching cleft (active site) on the enzyme. In this model, the enzyme's active site was a somewhat passive recipient of the substrate.
4. The induced fit model is a modified version of lock and key, where the substrate fits into the active site, and this initiates a change in the shape of the enzyme's active site so that the reaction can proceed.
5. (a) and (b) in any order, any two of:
 - Deviations from the optimum pH.
 - Excessively high temperature (heating).
 - Treatment with heavy metal ions, urea, organic solvents, or detergents.
 All these agents denature proteins by disrupting the non-covalent bonds maintaining the protein's functional secondary and tertiary structure. The covalent bonds providing the primary structure often remain intact but the protein loses solubility and the functional shape of the protein (its active site) is lost.
6. A mutation could result in a different amino acid being positioned in the polypeptide chain. The final protein may be folded incorrectly (incorrect tertiary and quaternary structure) and lose its biological function. **Note:** If the mutation is silent or in a non-critical region of the enzyme, biological function may not be affected.

Enzyme Reaction Rates (page 71)

- (a) An increase in enzyme concentration increases reaction rate.
(b) By manufacturing more or less (increasing or decreasing the rate of protein synthesis).
- (a) An increase in substrate concentration increases reaction rate to a point. Reaction rate does not continue increasing but levels off as the amount of substrate continues to increase.
(b) The reaction rate changes because after a certain substrate level the enzymes are fully saturated by substrate and the rate cannot increase any more.
- (a) An optimum temperature for an enzyme is the temperature at which enzyme activity is maximum.
(b) Most enzymes perform poorly at low temperatures because chemical reactions occur slowly or not at all at low temperatures (enzyme activity will reappear when the temperature increases; usually enzymes are not damaged by moderately low temperatures).
- (a) Optimum pH: pepsin: 1-2, trypsin: approx. 7.5-8.2, urease: approx. 6.5-7.0.
(b) The stomach is an acidic environment which is the ideal pH for pepsin.

Enzyme Cofactors and Inhibitors (page 72)

- Cofactors** are non-protein molecules or ions that are required for proper functioning of an enzyme either by altering the shape of the enzyme to complete the active site or by making the active site more reactive (improving the substrate-enzyme fit).
- (a) Arsenic, lead, mercury, cadmium.
(b) Heavy metals are toxic because they bind to the active sites of enzymes and permanently inactivate them. While the active site is occupied by the heavy metal the enzyme is non-functional. Because they are lost exceedingly slowly from the body, anything other than a low level of these metals is toxic.
- (a) Examples (any one of): nerve gases, cyanide, DDT, parathion, pyrethrins (insecticides).
(b) **Nerve gases** deactivate the enzyme acetylcholinesterase which is important in the functioning of nerves and muscles (it normally deactivates acetylcholine in synapses and prevents continued over-response of nerve and muscle cells).
Cyanide poisons the enzyme cytochrome oxidase, one of the enzymes in the electron transport system. It therefore stops cellular respiration.
DDT and other organochlorines: Inhibitors of key enzymes in the nervous system.
Pyrethrins: Insecticides which inactivate enzymes at the synapses of invertebrates. This has a similar over-excitation effect as nerve gases in mammals.
- In **competitive** inhibition, the inhibitor competes with the substrate for the enzyme's active site and, once in place, prevents substrate binding. A **noncompetitive** inhibitor does not occupy the active site but binds to some other part of the enzyme, making it less able to perform its function as an effective biological catalyst.
- Whilst noncompetitive inhibitors reduce the activity of the enzyme and slow down the reaction rate, **allosteric**

inhibitors block the active site altogether and prevent its functioning completely.

Industrial Production of Enzymes (page 73)

- (a) In the production of intracellular enzymes, the microbial cells must first be separated from the culture medium and then disrupted. The production of extracellular enzymes does not require this cellular disruption.
(b) Cellular disruption is required to release intracellular enzymes from within the cells. Extracellular enzymes are present in the medium after being secreted by the cells.
- A crude extract is cheaper to produce in cases where a highly purified product is not required.

Putting Enzymes to Use (page 74)

- (a) Cell free enzyme extracts generally show a high level of activity. This makes them an efficient option for industrial processes, especially those with a limited number of steps.
(b) A cell free extract might not be used if (one of):
 - The processes involved in production of the end product were complex (involving several intracellular enzymes).
 - The enzyme involved was unstable or inactive outside the cell.
- (a) Benefits of immobilized enzymes. Any two of:
 - Easy recovery of enzyme for reuse.
 - Easy harvesting of enzyme-free end-product.
 - Greater stability (protection of a solid matrix).
 - Continuous fermentation is possible
 - Keeps proteolytic enzymes apart so that they do not digest each other.
 - Lower cost (because enzymes can be reused).
 (b) Disadvantages of immobilized enzymes. Any of:
 - Immobilization may be difficult to achieve.
 - Immobilization may lower enzyme activity and reaction rates.
 - Immobilization technique may not be stable; enzymes may eventually wash away.
 (c) Factors affecting the rate of end-product harvest: supply of substrate, temperature, pH, method of immobilization (if any).
- Enzymes are proteins, therefore proteases could break each other down. Immobilization holds proteolytic enzyme molecules apart from each other on an inert material so that they do not interact. In this way, the active life of the enzymes is prolonged.
- Any of: Encapsulation may make it difficult for enzyme and substrate to interact. Covalent bonding may damage the enzyme or subtly interfere with the active site. Entrapment may affect charges on the enzyme and affect interaction with the substrate. The enzyme may also leak away. Reaction rates may be slowed if rates of diffusion of substrate and end-product into and out of a matrix are reduced. Adsorbed enzymes are not firmly attached and may wash away.

Applications of Enzymes (page 75)

- (a) The reaction would not proceed or would require

- high temperatures or pressures to make it proceed.
- (b) The reaction would proceed only slowly.
Both consequences add expense to a process.
2. Properties of microbial enzymes that make them suitable industrial catalysts. (a)-(c) any three of:
- Huge microbial diversity: Important because a wide variety of microbial enzymes are available.
 - Microbial culture is relatively straightforward, so the enzymes are cost effective to produce for industry.
 - The enzymes can be immobilized and so used repeatedly and recovered (thus reducing costs).
 - The enzymes often do not require highly specific conditions in which to operate, so industrial processes can proceed at standard temperatures and pressures. Specific enzymes are also available to catalyze reactions where specific conditions (e.g. high temperatures) are required.
3. Brief answers only (one enzyme example given; there are often others). Students might provide more detail.
- (a) **Chymosin** from GE yeast or bacteria (including *E. coli* (Chy-max in the US) and *Kluyveromyces lactis*).
- (b) Used to coagulate the milk protein, casein.
- (a) **Amyloglucosidases** from GE bacteria.
- (b) Used to speed up the conversion of starch to sugars to get a low-calorie beer. **Note: proteases**, from GE microbes are used to modify the proteins from the malt and prevent cloudiness in the finishing stage. These are in addition to the proteases arising naturally from the grain in germination, which solubilize the proteins in the grains and make the amino acids available to the yeast.
- (a) **Pectinases** from the soft-rot bacterium *Erwinia* or from GE *Aspergillus niger*.
- (b) Breaks down the soluble pectin chains remaining in pressed juice and reduces cloudiness.
- (a) **Citrate synthase** is produced by a mutant strain of the fungus *Aspergillus niger*.
- (b) Citrate synthase (also isocitrate dehydrogenase), catalyses the fermentation of sucrose (under nitrogen limitation) to citric acid, a widely used preservative and pH regulator in the food industry.
- (a) **Proteases** from *Bacillus subtilis*.
- (b) Break the peptide bonds in protein-based stains.
- (a) **Invertase** (sucrase) from *Saccharomyces* spp.
- (b) Converts sucrose to glucose and fructose (invert syrup) to produce a soft center in sweets.
- (a) **Glucose oxidase** from the fungus *Aspergillus niger*.
- (b) Used in medical biosensors for the detection of blood glucose level. Glucose oxidase catalyses the conversion of the glucose to gluconic acid.
- (a) **Proteases** from *Bacillus subtilis*.
- (b) Break the peptide bonds in proteins, and digesting the hair and tissue from animal hides.
- (a) **Lactase** from the bacterium *Kluyveromyces lactis*.
- (b) Converts lactose to glucose and galactose in low lactose dairy products.
- (a) **Ligninases** from white rot fungal species.
- (b) Breaks down the lignin in wood pulp and wood waste. Lignin is a complex molecule and several enzymes, including laccase, lignin peroxidase, and

manganese peroxidase are involved.

4. (a) Biosensors use biological material, e.g. an enzyme, to detect the presence or concentration of a particular substance. **Note:** The biological material is immobilized within a semi-conductor. Its activity (in response to the substrate), causes an ion change which is detected by a transducer, amplified, and displayed as a read-out.
- (b) An enzyme that uses alcohol as its substrate (e.g. alcohol dehydrogenase) could be immobilized in the biological recognition layer. The product of its activity (on alcohol) would produce a detectable change, which would be amplified and displayed as a read-out.
5. (a) Microbial proteases are used in the pre-tanning processes of leather manufacture (e.g. removing fat and hair from hides). The ease with which they can be produced and the wide range of enzymes available has reduced the costs of leather treatment since they need not be pure formulations to be effective. Microbial proteases are also safer and more environmentally-friendly than the toxic chemicals traditionally used in tanning (tannery effluent has long been a source of environmental pollution from a range of chemicals including lime, sodium sulfide, salt, and organic solvents and dyes).
- (b) Chymosin from microbial sources has replaced much of the rennet from calves stomachs traditionally used in cheese production. Chymosin produced from GE microbial sources is very pure and therefore more predictable in terms of its activity than its traditional rennet counterpart. Microbial chymosin can also be produced quickly, so fluctuating demands can be easily satisfied. Fewer calves are required when microbial sources of chymosin supplement the traditional sources and the cheese from made using microbial chymosin is acceptable to vegetarians and others who will not eat cheese made with calf rennet. These features have (respectively) improved the efficiency, cost effectiveness, and consumer appeal of the product made with microbial chymosin.
- (c) The use of fungal ligninases to treat wood waste has improved the environmental safety and reduced pollution over the traditional methods (such as organic sulfur compounds). Fungal treatment of wood waste effectively accelerates natural biodegradation processes and allows these to continue even at cooler temperatures. Wood waste treated in this way is suitable for use as compost or in mushroom production.

The Cell Theory (page 78)

1. Microscopes enabled cells to be seen and examined in detail. Microscopy opened up an entire new field: the study of cells and microorganisms.
2. Spontaneous generation referred to the arising of living matter from non-living (inanimate) material (e.g. blowflies arising from meat). It was discredited because closer examination of cells and their processes revealed how cells really arise, grow, and divide.

Characteristics of Life (page 79)

- Features in common: Cytoplasm, plasma membrane, metabolism (the cell's own cellular machinery).
- Size:** Viruses are very small: generally 50-500 times smaller than a typical prokaryotic cell and up to 5000 times smaller than a eukaryote cell.
 - Metabolism:** Cells have metabolic activity; there are chemical reactions taking place much of the time. A virus has no cytoplasm and no metabolism of its own. It relies on the metabolism of its host cell.
 - Organelles:** Viruses have no organelles unlike cells, most of which have organelles which carry out specific roles in the cell.
 - Genetic material:** Viruses have a single or double stranded chromosome which can be RNA or DNA. Cells have only double stranded DNA chromosomes. In eukaryotes the chromosomes are contained within a nuclear membrane.
 - Life cycle:** Outside a living cell viruses exist as inert particles, adopting a "living" program only when they invade a host cell and can take over the cellular machinery of the cell. At times, they may integrate into the host cell's chromosome and remain latent. Cells are generally either alive (when there is metabolic activity) or dead (no metabolic activity).
Note: There are exceptions to this generalization, e.g. bacterial endospores which are special resting stages with no metabolic activity.
- Viruses are generally considered non-living because they are non-cellular (cells being the unit structure of life) and they do not show all the eight characteristics of living things.

Types of Living Things (page 80)

- Autotrophic:** plant cells, some protist(an) cells, some bacterial cells.
 - Heterotrophic:** fungal cells, animal cells, some protist(an) cells, some bacterial cells, viruses.
- Prokaryotic cells are much smaller (and simpler) than the cells of eukaryotes.
 - Prokaryotic cells are bacterial cells while eukaryotic cells are all cell types other than bacteria and viruses. **Note:** More specifically, prokaryotes lack a distinct nucleus, have no membrane-bound organelles, have a cell wall usually containing peptidoglycan and their DNA is present as a single, naked chromosome.
- Fungi are plant-like in their appearance and habit (growth form, lack of movement, habitat etc.)
 - This classification was erroneous because fungi (unlike plants) lack chlorophyll, their cell walls contain chitin (not cellulose), and they are heterotrophic (not autotrophic).
- Protists often exhibit both animal-like and plant-like features and the group is very diverse in terms of nutrition, reproduction, and structure.
Note: From a phylogenetic point of view, the protists are not monophyletic and should be classified accordingly.

Bacterial Cells (page 81)

- (a) Locomotion. Flagella enable bacterial movement.

- Fimbriae are shorter, straighter, and thinner than flagella. They are used for attachment rather than locomotion.
- Bacterial cell wall lies outside the plasma (cell surface) membrane. It is a semi-rigid structure composed of a macromolecule called peptidoglycan, and contains varying amounts of lipopolysaccharides and lipoproteins.
 - The glycocalyx is a viscous, gelatinous layer which lies outside the cell wall. It usually comprises polysaccharide and/or polypeptide, but not peptidoglycan, and may be firmly or loosely attached to the wall.
- Bacteria usually reproduce by binary fission, where the DNA replicates and the cell then splits into two.
 - Conjugation differs from binary fission in that DNA is exchanged between one bacterial cell (the donor) and another (the recipient). The recipient cell gains DNA from the donor.
 - Conjugation allows bacteria that have acquired new genes (e.g. a beneficial mutation for antibiotic resistance) to pass on those genes to other (compatible) bacteria. This allows for rapid genetic change since mutations are not lost but are passed on to other bacteria. **Note:** The genes for antibiotic resistance are often carried on extra-chromosomal (plasmid) DNA, so that chances of gene transfer through conjugation are increased.
- Plasmids are used extensively in recombinant DNA technology. Being accessory to the main chromosome, the plasmid DNA can be manipulated easily. Using restriction enzymes, foreign genes (e.g. gene for producing insulin) can be spliced into a plasmid, which then carries out the instructions of the foreign gene.

Unicellular Eukaryotes (page 83)

- Summary for each organism under the given headings:
Amoeba:
Nutrition: Heterotrophic, food (e.g. bacteria) ingested by phagocytosis. Food digested in food vacuoles.
Movement: By pseudopodia (cytoplasmic projections).
Osmoregulation: Contractile vacuole.
Eyespot: Absent
Cell wall: Absent
Paramecium:
Nutrition: Heterotrophic (feeds on bacteria and small protists). Food digested in food vacuoles.
Movement: By beating of cilia.
Osmoregulation: Contractile vacuoles.
Eyespot: Absent
Cell wall: Absent
Euglena:
Nutrition: Autotrophic (photosynthetic), but can be heterotrophic when light deprived.
Movement: By flagella (one larger, which is labeled, and one very small, beside the gullet).
Osmoregulation: Contractile vacuole.
Eyespot: Present.
Cell wall: Absent, although there is a wall-like pellicle, which lies inside the plasma membrane and is flexible.
Chlamydomonas:
Nutrition: Autotrophic (photosynthetic).
Movement: By flagella.
Osmoregulation: Contractile vacuole.

Eyespot: Present.
Cell wall: Present.

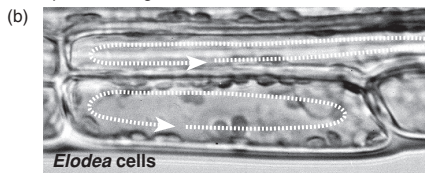
2. *Amoeba*, *Paramecium*, *Euglena*, *Chlamydomonas*.
3. An eye spot enables an autotroph to detect light so that it can move into (well lit) regions where it can photosynthesize.

Fungal Cells (page 84)

1. *In any order:* Cell wall of chitin; consist of filaments of cells (hyphae) that may form a network or mycelium; all are chemoheterotrophs, reproduction by spores.
2. Diploid yeast cells reproduce asexually by fission or budding (not involving spore formation). Sexual reproduction in yeasts involves the production of haploid ascospores which fuse to produce new diploid yeast cells. Filamentous fungi (molds such as *Rhizopus*) have a sexual phase characterized by fusion of gametes to produce a **zygospore** and an asexual phase characterized by production of asexual, haploid spores from a sporangium.
3. Many examples are possible: (a) and (b) any of:
 - *Penicillium* mold: production of antibiotics.
 - *Streptomyces* mold: production of antibiotics.
 - *Saccharomyces* spp. esp. *Saccharomyces cerevisiae*: production of alcoholic beverages.
 - *Aspergillus* spp.: production of industrial enzymes.

Plant Cells (page 85)

1. A: Nucleus C: Nucleus
B: Cell wall D: Chloroplasts
2. (a) Cytoplasmic streaming is the rapid movement of cytoplasm within eukaryotic cells, seen most clearly in plant and algal cells.

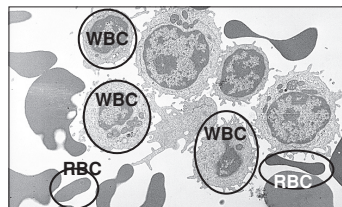


3. (a)-(c) any three of:
 - Starch (branched carbohydrate) granules stored in amyloplasts (energy store)
 - Chloroplasts, discrete plastids containing the pigment chlorophyll, involved in photosynthesis.
 - Large vacuole, often central (vacuoles are present in animal cells, but are only small).
 - Cell wall of cellulose forming the rigid, supporting structure outside the plasma membrane.
 - Plasmodesmata

Animal Cells (page 86)

1. A: Nucleus
B: Plasma membrane
C: Nucleus

2. (a)



White blood cells (WBC) & red blood cells (RBC)

- (b) Any of the following reasons: The RBCs have no nucleus and they are smaller than the white blood cells. The white blood cells have extensions of the plasma membrane (associated with being mobile and phagocytic), are larger than the RBCs, and have a nucleus.
3. Centrioles (although these are present in lower plants, they are absent from higher plants). They are microtubular structures responsible for forming the poles and the spindles during cell division.

Cell Sizes (page 87)

1. (a) *Amoeba*: 300 μm 0.3 mm
(b) Foraminiferan: 400 μm 0.4 mm
(c) *Leptospira*: 7-8 μm 0.007-0.008 mm
(d) Epidermis: 120 μm 0.12 mm
(e) *Daphnia*: 2500 μm 2.5 mm
(f) *Papillomavirus*: 0.13 μm 0.00013 mm
2. *Papillomavirus*, *Leptospira*, Epidermis, *Amoeba*, Foraminiferan, *Daphnia*
3. Epidermis (possibly), *Amoeba*, Foraminiferan, *Daphnia*
4. (a) 0.00025 mm (b) 0.45 mm (c) 0.0002 mm

Cell Structures and Organelles (page 88)

- (b) **Name:** Ribosome
Location: Free in cytoplasm or bound to rough ER
Function: Synthesize polypeptides (=proteins)
Present in plant cells: Yes
Present in animal cells: Yes
Visible under LM: No
- (c) **Name:** Mitochondrion
Location: In cytoplasm as discrete organelles
Function: Site of cellular respiration (ATP formation)
Present in plant cells: Yes
Present in animal cells: Yes
Visible under LM: Not with most standard school LM, but can be seen using high quality, high power LM.
- (d) **Name:** Golgi apparatus
Location: In cytoplasm associated with the smooth endoplasmic reticulum, often close to the nucleus.
Function: Final modification of proteins and lipids. Sorting and storage for use in the cell or packaging molecules for export.
Present in plant cells: Yes
Present in animal cells: Yes
Visible under LM: Not with most standard school LM, but may be visible using high quality, high power LM.
- (e) **Name:** Endoplasmic reticulum (in this case, rough ER)
Location: Penetrates the whole cytoplasm
Function: Involved in the transport of materials (e.g.

proteins) within the cell and between the cell and its surroundings.

Present in plant cells: Yes

Present in animal cells: Yes

Visible under LM: No

- (f) **Name:** Chloroplast

Location: Within the cytoplasm

Function: The site of photosynthesis

Present in plant cells: Yes

Present in animal cells: No

Visible under LM: Yes

- (g) **Name:** Cytoskeleton

Location: Throughout cytoplasm

Function: Provides structure and shape to a cell, responsible for cell movement (e.g. during muscle contraction), and provides intracellular transport of organelles and other structures.

Present in plant cells: Yes

Present in animal cells: Yes

Visible under LM: No

- (h) **Name:** Cellulose cell wall

Location: Surrounds the cell and lies outside the plasma membrane.

Function: Provides rigidity and strength, and supports the cell against changes in turgor.

Present in plant cells: Yes

Present in animal cells: No

Visible under LM: Yes

- (i) **Name:** Cell junctions (an animal example is given)

Location: At cell membrane surface, connecting adjacent cells.

Function: Depends on junction type. Desmosomes fasten cells together, gap junctions act as communication channels between cells, and tight junctions prevent leakage of extracellular fluid from layers of epithelial cells.

Present in plant cells: Yes, as plasmodesmata

Present in animal cells: Yes

Visible under LM: No

- (j) **Name:** Lysosome and food vacuole (given)

Lysosome

Location: Free in cytoplasm.

Function: Ingests and destroys foreign material. Able to digest the cell itself under some circumstances.

Present in plant cells: Yes but variably (vacuoles may have a lysosomal function in some plant cells).

Present in animal cells: Yes

Visible under LM: No

Vacuole (a food vacuole in an animal cell is shown, so students may answer with respect to this).

Location: In cytoplasm.

Function: In plant cells, the vacuole (often only one) is a large fluid filled structure involved in storage and support (turgor). In animal cells, vacuoles are smaller and more numerous, and are involved in storage (of water, wastes, and soluble pigments).

Present in plant cells: Yes, as (a) large structure(s).

Present in animal cells: Yes, smaller, more numerous

Visible under LM: Yes in plant cells, no in animal cells.

- (k) **Name:** Nucleus

Location: Discrete organelle, position is variable.

Function: The control center of the cell; the site of the nuclear material (DNA).

Present in plant cells: Yes

Present in animal cells: Yes

Visible under LM: Yes.

- (l) **Name:** Centrioles

Location: In cytoplasm, usually next to the nucleus.

Function: Involved in cell division (probably in the organization of the spindle fibers).

Present in plant cells: Variably (absent in higher plants)

Present in animal cells: Yes

Visible under LM: No.

- (m) **Name:** Cilia and flagella (given)

Location: Anchored in the cell membrane and extending outside the cell.

Function: Motility.

Present in plant cells: No

Present in animal cells: Yes

Visible under LM: Variably (depends on magnification and preparation/fixation of material).

Differential Centrifugation (page 91)

- Cell organelles have different densities and spin down at different rates. Smaller organelles take longer to spin down and require a higher centrifugation speed to separate out.
- The sample is homogenized (broken up) before centrifugation to rupture the cell surface membrane, break open the cell, and release the cell contents.
- (a) Isotonic solution is needed so that there are no volume changes in the organelles.
(b) Cool solution prevent self digestion of the organelles by enzymes released during homogenization.
(c) Buffered solution prevents pH changes that might denature enzymes and other proteins.
- (a) Ribosomes and endoplasmic reticulum
(b) Lysosomes and mitochondria
(c) Nuclei

Identifying Cell Structures (page 92)

- (a) Cytoplasm (f) Cell wall
(b) Vacuole (g) Chromosome
(c) Starch granule (h) Nuclear membrane
(d) Chloroplast (i) Endoplasmic reticulum
(e) Mitochondria (j) Plasma membrane
- 9 cells (1 complete cell, plus the edges of 8 others)
- Plant cell; it has chloroplasts and a cell wall. It also has a highly geometric cell shape.
- (a) Cytoplasm located between the plasma membrane and nuclear membrane (extranuclear).
(b) Composition of cytoplasm: A watery soup of dissolved substances. In eukaryotic cells, organelles are found in the cytoplasm. Cytoplasm = cytosol (including cytoskeleton) + organelles.
(c) Prokaryotic cells do not have a defined nucleus.
- (a) Starch granules, which occur within specialized plastids called leucoplasts. Starch granules are non-living inclusions, deposited as a reserve energy store.
(b) Vacuoles, which are fluid filled cavities bounded by a single membrane. Plant vacuoles contain cell sap; an aqueous solution of dissolved food material, ions, waste products, and pigments. **Note:** Young plant cells (such as the one pictured) usually have several small vacuoles, which unite in a mature cell to form a large, permanent central vacuole.

Optical Microscopes (page 93)

- Compound microscope (a)-(h) and dissecting microscope (i)-(m) as follows:

(a) Eyepiece lens	(h) In-built light source
(b) Arm	(i) Eyepiece lens
(c) Coarse focus knob	(j) Eyepiece focus
(d) Fine focus knob	(k) Focus knob
(e) Objective lens	(l) Objective lens
(f) Mechanical stage	(m) Stage
(g) Condenser	
- Phase contrast: used where the specimen is transparent (to increase contrast between transparent structures). **Note:** It is superior to dark field because a better image of the interior of specimens is obtained.
- Plant cell, any two of: cell wall, nucleus (may see chromatin if stained appropriately), vacuole, cell membrane (high magnification), Golgi apparatus, mitochondria (high magnification), chloroplast, cytoplasm (if stained), nuclear envelope (maybe).
 - Animal cell, any two of: nucleus (may see chromatin if stained appropriately), centriole, cell membrane (high magnification), Golgi apparatus, mitochondria (high magnification), cytoplasm (if stained), nuclear envelope (maybe).
- Any one of: Ribosomes, microtubules, endoplasmic reticulum, Golgi vesicles (free), nuclear envelope as two layers, lysosomes (animal cells). Also detail of organelles such as mitochondria and chloroplasts.
- Leishman's stain
 - Schultz's solution / iodine solution
 - Schultz's solution
 - Aniline sulfate / Schultz's solution
 - Methylene blue
 - Schultz's solution
- 600X magnification
 - 600X magnification
- Bright field microscopes produces a flat (2-dimensional) image, which looks through a thin, transparent sample. Dissecting microscopes produces a 3-dimensional image, which looks at the surface details.
- Magnification** is the number of times larger an image is than the specimen. **Resolution** is the degree of detail which can be achieved. The limit of resolution is the minimum distance by which two points in a specimen can be separated and still be distinguished as separate points. **Note:** By adding stronger, or more, lenses, a light microscope can magnify an image many thousands of times but its resolution is limited. Electron microscopes have a greater resolving power than light microscopes because of the very short wavelength of the electrons used.

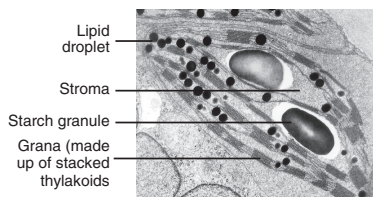
Electron Microscopes (page 95)

- The limit of resolution (see #8 previously) is related to wavelength (about 0.45X the wavelength). The shortest visible light has a wavelength of about 450 nm giving a resolution of 0.45 x 450 nm; close to 200 nm. Points less than 200 nm apart will be perceived as one point or a blur. Electron beams have a much shorter wavelength than light so the resolution is much greater (points that are 0.5 nm apart can be distinguished as separate points; a resolving power 400X that of a LM).

- TEM: Used to (any of): show cell ultrastructure i.e. organelles; to investigate changes in the number, size, shape, or condition of cells and organelles i.e. demonstrate cellular processes or activities; to detect the presence of viruses in cells.
 - SEM: Used to (any of): show the surface features of cells, e.g. guard cell surrounding a stoma; to show the surface features of entire organisms for identification purposes (often used for invertebrates and viruses); for general identification by surface feature, e.g. pollen grains in paleoclimate research.
 - Bright field (compound): Used for (any of): examining prepared sections of tissue for cellular detail; for examining living tissue for large scale movements, e.g. blood flow in capillaries or cytoplasmic streaming.
 - Dissecting: Used for (any of): examining living specimens for surface detail and structures; sorting material from samples (e.g. leaf litter or stream invertebrates); dissecting a small organism where greater resolution than the naked eye is required.
- | | |
|-------------------|-------------------|
| A TEM | E SEM |
| B Bright field LM | F Bright field LM |
| C TEM | G Dissecting LM |
| D Bright field LM | H SEM |

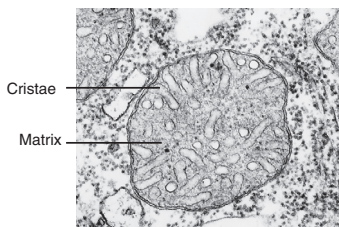
Interpreting Electron Micrographs (page 97)

- Chloroplast
 - Plant cells, particularly in leaf and green stems.
 - Function: Site of photosynthesis. Captures solar energy to build glucose from carbon dioxide and water.
 - Any two of the following:

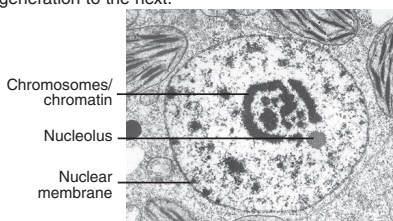


- Golgi apparatus
 - Plant and animal cells
 - Function: Packages substances to be secreted by the cell. Forms a membrane vesicle containing the chemicals for export from the cell (e.g. nerve cells export neurotransmitters; endocrine glands export hormones; digestive gland cells export enzymes).
- Mitochondrion
 - Plant and animal cells (most common in cells that have high energy demands, such as muscle).
 - Function: Site of most cellular respiration, which releases energy from food (glucose) to fuel most cellular reactions (i.e. metabolism).

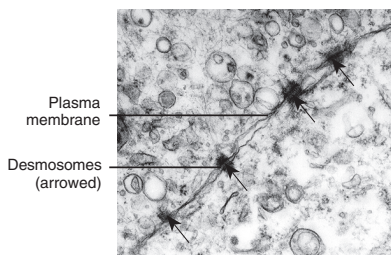
(d)



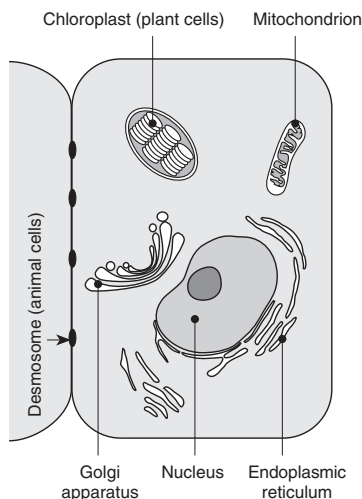
4. (a) Endoplasmic reticulum
 (b) Plant and animal cells (eukaryotes)
 (c) Function: Site of protein synthesis (translation stage). Transport network that moves substances through its system of tubes. Many complex reactions need to take place on the surface of the membranes.
 (d) Endoplasmic reticulum structure: ribosomes.
5. (a) Nucleus
 (b) Plant and animal cells (eukaryotes)
 (c) Function: Controls cell metabolism (all the life-giving chemical reactions), and functioning of the whole organism. These instructions are inherited from one generation to the next.
 (d)



6. (a) Function: Controls the entry and exit of substances into and out of the cell. Maintains a constant internal environment.
 (b)



7. Generalized cell:



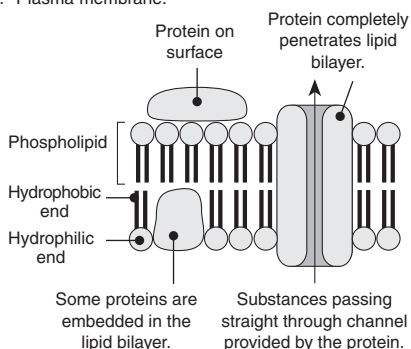
Cell Processes (page 100)

- Golgi apparatus
 - Cytoplasm, mitochondria
 - Plasma membrane, vacuoles
 - Plasma membrane, vacuoles
 - Endoplasmic reticulum, ribosomes, nucleus
 - Chloroplasts
 - Centrioles, nucleus
 - Lysosomes
 - Plasma membrane, Golgi apparatus
- Metabolism** describes all the chemical processes of life taking place inside the cell. Examples include cellular respiration, fatty acid oxidation, photosynthesis, digestion, urea cycle, and protein synthesis.

The Structure of Membranes (page 101)

- Membranes are composed of a phospholipid bilayer in which are embedded proteins, glycoproteins, and glycolipids. The structure is relatively fluid and the proteins are able to move within this fluid matrix.
 - The Davson-Danielli model described membranes as a lipid bilayer with a coating of protein. This model was modified when freeze-fracture techniques showed that the proteins were embedded in the membrane rather than coating the outside. As described in the fluid mosaic model, some proteins span the width of the membrane, some are on the outside or the inside.
- Membranes perform a number of diverse roles. The plasma membrane forms the outer limit of the cell and contains the proteins that confer cellular recognition. It also controls the entry and exit of materials into and out of the cell. Intracellular membranes keep the cytoplasm separate from the extracellular spaces and provide compartments within cells for localization of metabolic (enzymatic) reactions. They also provide a surface for the attachment of the enzymes involved in metabolism.

3. (a) Any of: Golgi apparatus, mitochondria, chloroplasts, endoplasmic reticulum (rough or smooth), nucleus, vacuoles, lysosomes.
(b) Depends on choice: Generally the membrane's purpose is to compartmentalize the location of enzymatic reactions, to control the entry and exit of substances that the organelle operates on, and/or to provide a surface for enzyme attachment.
4. (a)-(c) any three of the following not already chosen: Golgi apparatus, mitochondria, vacuoles, endoplasmic reticulum, chloroplasts, lysosomes.
5. (a) Cholesterol lies between the phospholipids and prevents close packing. It functions to keep membranes more fluid. The greater the amount of cholesterol in the membrane the greater its fluidity.
(b) At temperatures close to freezing, high proportions of membrane cholesterol is important in keeping membranes fluid and functioning.
6. (a)-(c) in any order: oxygen, food (glucose), minerals and trace elements, water.
7. (a) Carbon dioxide (b) Nitrogenous wastes
8. Plasma membrane:



The Role of Membranes in Cells (page 103)

1. Membrane systems and organelles provide compartments within cells which allow enzymatic reactions in the cell to be localized. This achieves greater efficiency in cell function and keeps potentially harmful reactions and substances (e.g. hydrogen peroxide) contained.
2. (a) Golgi apparatus
(b) lysosome
(c) mitochondrion
(d) rough endoplasmic reticulum
(e) smooth endoplasmic reticulum
(f) chloroplast
3. Membrane surface area is increased within cells and organelles by invaginations or by a long flattened shape which increases the surface area to volume ratio.
4. (a) High membrane surface area provides a greater area over which membrane-bound reactions can occur. This increases the speed and efficiency with which metabolic reactions can take place.

- (b) Channel and carrier proteins facilitate selective transport of substances through membranes. They can help to speed up the transport of substances into and out of the cell, especially for enzymatic reactions requiring a steady supply of substrate and constant removal of end-product, e.g. ADP supply to the mitochondrion during cellular respiration.
5. (a) Non-polar (lipid-soluble) molecules are able to dissolve in the lipid bilayer structure of the membrane and diffuse easily into the cell whereas the polar (lipid-insoluble) molecules have to be actively transported through the membrane.
(b) Transportation of lipid-soluble molecules by diffusion alone into a cell is much quicker than that of lipid-insoluble molecules that have to be actively transported across the plasma membrane. This also increases the speed and efficiency with which metabolic reactions can take place.

Modification of Proteins (page 105)

1. (a) **Glycoproteins** are proteins with attached carbohydrates (often relatively small polymers of sugar units).
(b) In any order, three roles of glycoproteins:
 - **Intercellular recognition:** Present on cell surfaces for recognition between cells (when cells interact to form tissues and for immune function).
 - **Transport:** Embedded in cell membranes to transport molecules through the membrane (the sugars help to maintain the position of the glycoprotein in the membrane).
 - **Regulation:** Secretory proteins from glands with a role in regulation, e.g. many pituitary hormones.
2. (a) **Lipoproteins** are proteins with attached fatty acid molecules.
(b) Lipoproteins transport lipid molecules in the plasma between different organs in the body.
3. Proteins made on free ribosomes are released directly into the cytoplasm; there is no facility for attachment of carbohydrate as this generally requires a packaging region (the Golgi apparatus).
4. Protein orientation in the membrane is important because it is usually critical to the functional role of the protein, e.g. in intercellular recognition or transport.

Packaging Macromolecules (page 106)

1. Large organic polymers made up of many repeating units of smaller molecules. They have a high molecular weight. Examples include proteins and nucleic acids.
2. Polypeptides are synthesized by membrane bound ribosomes so that they can be easily threaded through the ER membrane into the cisternal space of the ER. Here they are in place for subsequent modification, packaging and export.
3. The carbohydrates attached to glycoproteins aid in the recognition or function of the protein so that it is transported to the correct destination and performs its appropriate functional role.
4. (a) Rough ER: Ribosomes on the rough ER assemble the proteins destined for secretion.
(b) Smooth ER: Synthesis of lipids, e.g. steroid

hormones and phospholipids, and packages them into transport vesicles.

- (c) Golgi apparatus: Receives transport vesicles. Modifies, stores, and transports molecules for export around or from the cell.
- (d) Transport vesicles: These bud off the ER and move substances to the Golgi apparatus.

Active and Passive Transport (page 107)

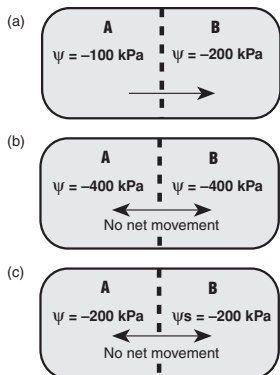
1. **Passive transport** requires no energy input from the cell; materials follow a concentration gradient.
Active transport requires considerable amounts of energy (ATP) to make materials go in a direction they would not normally go (at least at the rate required).
2. Gases moving by diffusion: oxygen, carbon dioxide.
3. (Any one of): Cells in the digestive (exocrine) glands of the stomach, pancreas, upper small intestine (duodenum); endocrine glands (e.g. adrenal glands); salivary glands.
4. (a) Protozoan (any one of): *Amoeba*, *Paramecium*
(b) In *Paramecium*, a food vacuole develops at the end of the oral groove and is pinched off to circulate within the cell. In *Amoeba*, the pseudopodia engulf a food particle and a vacuole is formed where the membrane pinches off after the particle is engulfed.
(c) Human cell: Phagocyte (white blood cell).

Diffusion (page 108)

1. (a) Large surface area (b) Thin membrane
2. Concentration gradients are maintained by (any one of):
- Constant use or transport away of a substance on one side of a membrane (e.g. use of ADP in mitochondria).
- Production of a substance on one side of a membrane (e.g. production of CO_2 by respiring cells).
3. Ionophores allow the preferential passage of some molecules but not others.

Osmosis and Water Potential (page 109)

1. Zero
2. and 3

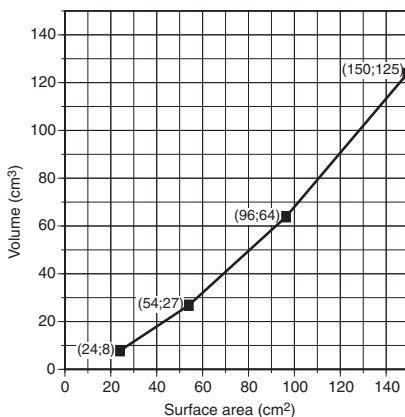


4. (a) Hypotonic
(b) Fluid replacements must induce the movement of water into the cells and tissues (which are dehydrated and therefore have a more negative water potential than the drink). **Note:** Many sports drinks are isotonic. Depending on the level of dehydration involved, these drinks are more effective when diluted.
5. *Paramecium* is hypertonic to the surrounding freshwater environment; water constantly enters the cell. This must be continually pumped out (by contractile vacuoles).
6. (a) Pressure potential generated within plant cells provides the turgor necessary for keeping unligified plant tissues supported.
(b) Without cell turgor, soft plant tissues (soft stems and flower parts for example) would lose support and wilt. **Note** that some tissues are supported by structural components such as lignin.
7. Animal cells are less robust than plant cells against changes in net water content: Excess influx will cause bursting and excess loss causes crenulation.
8. (a) Water will move into the cell and it will burst (lyse).
(b) The cell would lose water and the plasma membrane would crinkle up (crenulate).
(c) Water will move into the cell and it will burst (lyse).
9. Malarial parasite: **isotonic** to blood.

Surface Area and Volume (page 111)

1.

	Surface area	Volume	Ratio
3 cm:	$3 \times 3 \times 6 = 54$	$3 \times 3 \times 3 = 27$	2.0 to 1
4 cm:	$4 \times 4 \times 6 = 96$	$4 \times 4 \times 4 = 64$	1.5 to 1
5 cm:	$5 \times 5 \times 6 = 150$	$5 \times 5 \times 5 = 125$	1.2 to 1
2. Surface area to volume graph:



3. Volume
4. Increasing size leads to less surface area for a given volume. The surface area to volume ratio decreases.
5. Less surface area at the cell surface. This is the gas exchange surface, therefore large cells will have

difficulty moving materials in and out of the cell in the amounts required to meet demands. This is what limits a cell's maximum size. **Note:** Eukaryote cells are typically about 0.01-0.1 mm in size, but some can be bigger than 1 mm. The largest cell is the female sex cell (ovum) of the ostrich, which averages 15-20 cm in length. Technically a single cell, it is atypical in size because almost the entire mass of the egg is food reserve in the form of yolk, which is not part of the functioning structure of the cell itself.

Ion Pumps (page 113)

1. If an animal cell (not protected by a rigid cell wall), contains excessive quantities of ions, it may take up so much water by osmosis that it would swell up and burst.
2. An ion exchange pump creates an unequal balance of ions across the membrane. The transport of other molecules (e.g. sucrose) can be coupled to the passive diffusion of an ion (e.g. H^+) as it diffuses down its concentration gradient.
3. ATP is required to move ions **against** their concentration gradient (an energy requiring process). (When a phosphate is transferred from the ATP to the carrier protein, a shape change in the protein brings about the transfer of the bound molecule (e.g. an ion) from one side of the membrane to the other).
4. Coupled pumps operate in (any one of):
 - Loading of sucrose into the **phloem sieve tube cells** (coupled to a proton pump).
 - Transport of glucose across the **epithelium** of the gut into the blood (coupled to a sodium pump).

Exocytosis and Endocytosis (page 114)

1. **Phagocytosis** is the engulfment of solid material by endocytosis whereas **pinocytosis** is the uptake of liquids or fine suspensions by endocytosis.
2. Phagocytosis examples (any of):
 - Feeding in *Amoeba* by engulfment of material using cytoplasmic extensions called pseudopodia.
 - Ingestion of old red blood cells by Kupffer cells in the liver.
 - Ingestion of bacteria and cell debris by neutrophils and macrophages (phagocytic white blood cells).
3. Exocytosis examples (any of):
 - Secretion from specialized cells in multicellular organisms, e.g. hormones from endocrine cells, digestive secretions from exocrine cells.
 - Expulsion of wastes from unicellular organisms e.g. *Paramecium* and *Amoeba* expelling residues from food vacuoles.
4. Any type of cytolysis (unlike diffusion) is an active process involving the use of ATP. Low oxygen inhibits oxidative metabolism and lowers the energy yield from the respiration of substrates (ATP availability drops).
5. (a) **Oxygen:** diffusion.
 (b) **Cellular debris:** phagocytosis.
 (c) **Water:** osmosis.
 (d) **Glucose:** facilitated diffusion.

Cell Division (page 116)

1. (a) **Mitosis:** Cell division for growth and repair produces cells with 2N chromosome number.
 (b) **Meiosis:** Cell division for producing gametes (sperm, pollen, eggs) with 1N chromosome number.
2. A **zygote** results from the fertilization of an egg and sperm cell; it is diploid and gives rise (through mitosis and cellular differentiation) to a new individual.
3. In **spermatogenesis**, the nucleus of the germ cell divides twice to produce four similar sized gametes (sperm cells). In **oogenesis**, the two divisions are not equal and only one of the four nuclei (and most of the cytoplasm) produce the egg cell.

Mitosis and the Cell Cycle (page 117)

1. A. Anaphase
 B. Prophase
 C. Late metaphase (early anaphase is also acceptable).
 D. Late anaphase
 E. Cytokinesis (late telophase is also acceptable).
2. Replicate the DNA to form a second chromatid. Coil up into visible chromosomes to avoid tangling.
3. A. Interphase: The stage between cell divisions (mitoses). Just before mitosis, the DNA is replicated to form an extra copy of each chromosome (still part of the same chromosome as an extra chromatid).
 B. Late prophase: Chromosomes condense (coil and fold up) into visible form. Centrioles move to opposite ends of the cell.
 C. Metaphase: Spindle fibers form between the centrioles. Chromosomes attach to the spindle fibers at the cell 'equator'.
 D. Late anaphase: Chromatids from each chromosome are pulled apart and move in opposite directions, towards the centrioles.
 E. Telophase: Chromosomes begin to unwind again. Two new nuclei form. The cell plate forms across the midline where the new cell wall will form.
 F. Cytokinesis: Cell cytoplasm divides to create two distinct 'daughter cells' from the original cell. It is in this form for most of its existence, and carries out its designated role (normal function).

Apoptosis: Programmed Cell Death (page 119)

1. Syndactyly arises when the rate of apoptosis in the developing limb has been too low to remove the tissue between the digits before the close of the developmental sequence (hence the lack of differentiation between the two toes, which remain partly joined).
2. Any one of the reasons from the following explanation: Apoptosis is a carefully regulated process, which occurs in response to particular signalling factors. Necrosis, in contrast, is the result of traumatic damage. Apoptosis results in membrane-bound cell fragments whereas necrosis results in lysing and spillage of cell contents. Apoptosis results in cell shrinkage and contraction of the chromatin, which does not occur in necrosis.
3. Roles of apoptosis, (a) and (b) any two of the following

in any order:

- Resorption of the larval tail during amphibian metamorphosis.
- Sloughing of the endometrium during menstruation.
- The formation of the proper connections (synapses) between neurons in the brain (this requires that surplus cells be eliminated by apoptosis).
- Controlled removal of virus-infected cells.
- Controlled removal of cancerous cells.

Cancer: Cells out of Control (page 120)

1. Cancerous cells have lost control of the genetic mechanisms regulating the cell cycle so that the cells become 'immortal'. They also lose their specialized functions and are unable to perform their roles.
2. The cell cycle is normally controlled by two types of gene: proto-oncogenes, which start cell division and are required for normal cell development, and **tumor-suppressor genes**, which switch cell division off. Tumor suppressor genes will also halt cell division if the DNA is damaged and, if the damage is not repairable, will bring about a programmed cell suicide (apoptosis).
3. Normal controls over the cell cycle can be lost if either the proto-oncogenes or the tumor suppressor genes acquire mutations. Mutations to the proto-oncogenes, with the consequent formation of **oncogenes**, results in uncontrolled cell division. Mutations to the tumor-suppressor genes results in a failure to regulate the cell repair processes and a failure of the cell to stop dividing when damaged.

Differentiation of Human Cells (page 121)

1. 230 different cell types
2. 50 cell divisions
3. 100 billion cells
4. (Any one of): Skin cells, intestinal epithelial cells, blood (stem) cells.
5. (Any one of): Nerve cells, bone cells, kidney cells.
6. (a) **Germ line** is the cell line that, early in development, becomes differentiated from the somatic cell line and has the potential to form gametes.
(b) Germ cells will produce gametes (eggs and sperm) and must be essentially unspecialized cells. This is necessary so that none of the genes that are needed to produce the 230 specialized cells in new offspring are turned off before they are needed.
7. (a) A **clone** is a copy of a cell (or complete organism) with a genetic make-up that is identical to the single parent cell it was created from.
(b) As for 6(b): None of the genes required to produce specialized cells have been turned off.
8. Cancerous cells are cells that have lost control of the regulatory processes that govern the cell's function. Instead they become generalized cells that lose their tissue identity, pulling away from cells around them and undergoing cell division at a rapid rate.
9. At certain stages in the sequence of cell divisions as the embryo grows, some genes get switched on while

others get switched off permanently, causing the cells to take on specialized functions.

Stem Cells and Tissue Engineering (page 123)

1. (a) They have the ability to self renew while maintaining an undifferentiated state.
(b) A stem cell has the capacity to differentiate into specialized cells types (potency).
2. Embryonic stem cells are pluripotent and can form over 220 cell types in the three primary germ layers (ectoderm, endoderm, mesoderm). Their potential for medical application is vast as they can theoretically be used to replace most damaged cell and tissue types. Adult stem cells are multipotent and can divided only into a limited number of cell types, mainly those of the blood, heart and nerves. Their medical applications are more limited than ESC, but because there are fewer ethical issues involved ASC are already being used to treat medical problems such as leukaemia.
3. The main purpose of ASC are to maintain and repair the tissue in which they are found. Some examples are:
 - Hematopoietic stem cells give rise to all the types of blood cells, red blood cells, lymphocytes, leukocytes and platelets.
 - Bone marrow stromal cells (mesenchymal stem cells) give rise to a variety of cell types including bone cells (osteocytes), cartilage cells (chondrocytes), fat cells (adipocytes) and connective tissue cells such as tendons.
 - Neural stem cells in the brain can produce nerve cells (neurons) and the non-neuronal cells astrocytes and oligodendrocytes.
 - Epithelial stem cells that line the digestive tract give rise to absorptive cells, goblet cells, Paneth cells and enteroendocrine cells.
 - Skin stem cells in the basal layer of the epidermis form keratinocytes which protect the skin. Follicular stem cells at the base of hair follicles give rise to the hair follicle and epidermal cells.
4. Advantages of using embryonic stem cell cloning in tissue engineering (any one of):
 - This technology will provide a disease-free and plentiful supply of (tissue-typed, compatible) cells.
 - Embryonic stem cells have the ability to develop and form all the tissues of the body. Theoretically, there should be no shortage of specific cell types.
 - It will improve the possibility of creating semi-synthetic living organs for use as replacement parts.
5. A tissue engineered skin product allows victims to make skin akin to their own and thereby circumventing any rejection problems.
6. Present medical applications of tissue engineering include the production of artificial skin, which is currently approved as a biomedical device and is used for grafts in the treatment of burns and diabetic ulcers. Tissue engineering is also used to create artificial blood vessels for use in cardiac surgery, and it can be used in the repair of severely damaged bone tissue. In the future, tissue engineering may be used to treat degenerative nerve diseases and to create semi-synthetic living organs for use as replacement parts for organ transplants.

Human Cell Specialization (page 125)1. (b) **Erythrocyte:**

Features: Biconcave cell, lacking mitochondria, nucleus, and most internal membranes. Contains the oxygen-transporting pigment, hemoglobin.
Role: Uptake, transport, and release of oxygen to the tissues. Some transport of CO₂. Lack of organelles creates more space for oxygen transport. Lack of mitochondria prevents oxygen use.

(c) **Retinal cell:**

Features: Long, narrow cell with light-sensitive pigment (rhodopsin) embedded in the membranes.
Role: Detection of light: light causes a structural change in the membranes and leads to a nerve impulse (result is visual perception).

(d) **Skeletal muscle cell(s):**

Features: Cylindrical shape with banded myofibrils. Capable of contraction (shortening).
Role: Move voluntary muscles acting on skeleton.

(e) **Intestinal epithelial cell:**

Features: Columnar cell with a high surface area as a result of fingerlike projections (microvilli).
Role: Absorption of digested food.

(f) **Motor neuron cell:**

Features: Cell body with a long extension (the axon) ending in synaptic bodies. Axon is insulated with a sheath of fatty material (myelin).
Role: Rapid conduction of motor nerve impulses from the spinal cord to effectors (e.g. muscle).

(g) **Spermatoocyte:**

Features: Motile, flagellated cell with mitochondria. Nucleus forms a large proportion of the cell.
Role: Male gamete for sexual reproduction. Mitochondria provide the energy for motility.

(h) **Osteocyte:**

Features: Cell with calcium matrix around it. Fingerlike extensions enable the cell to be supplied with nutrients and wastes to be removed.
Role: In early stages, secretes the matrix that will be the structural component of bone. Provides strength.

Plant Cell Specialization (page 126)1. (b) **Pollen grain:**

Features: Small, lightweight, often with spikes.
Role: Houses male gamete for sexual reproduction.

(c) **Palisade parenchyma cell:**

Features: Column-shaped cell with chloroplasts.
Role: Primary photosynthetic cells of the leaf.

(d) **Epidermal cell:**

Features: Waxy surface on a flat-shaped cell.
Role: Provides a barrier to water loss on leaf.

(e) **Vessel element:**

Features: Rigid remains of a dead cell. No cytoplasm. End walls perforated. Walls are strengthened with lignin fibers.
Role: Rapid conduction of water through the stem. Provides support for stem/trunk.

(f) **Stone cell:**

Features: Very thick lignified cell wall inside the primary cell wall. The cytoplasm is restricted to a small central region of the cell.
Role: Protection of the seed inside the fruit.

(g) **Sieve tube member:**

Features: Long, tube-shaped cell without a nucleus. Cytoplasm continuous with other sieve cells above and below it. Cytoplasmic streaming is evident.
Role: Responsible for translocation of sugars etc.

(h) **Root hair cell:**

Features: Thin cuticle with no waxy layer. High surface area relative to volume.

Role: Facilitates the uptake of water and ions.

Levels of Organization (page 127)1. **Animals**

- (a) **Organ system:** Nervous system, reproductive system
- (b) **Organs:** Brain, heart, spleen
- (c) **Tissues:** Blood, bone, cardiac muscle, cartilage, squamous epithelium
- (d) **Cells:** Leukocyte, mast cell, neuron, Schwann cell
- (e) **Organelles:** Lysosome, ribosomes
- (f) **Molecular:** Adrenaline, collagen, DNA, phospholipid

2. **Plants**

- (a) **Organs:** Flowers, leaf, roots
- (b) **Tissues:** Collenchyma*, mesophyll, parenchyma*, phloem, sclerenchyma
- (c) **Cells:** Companion cells, epidermal cell, fibers, tracheid
- (d) **Organelles:** Chloroplasts, ribosomes
- (e) **Molecular:** Pectin, cellulose, DNA, phospholipid

* **Note:** Parenchyma and collenchyma are simple tissues comprising only one type of cell (parenchyma and collenchyma cells respectively). Simple plant tissues are usually identified by cell name alone.

Animal Tissues (page 128)

1. The organization of cells into specialized tissues allows the tissues to perform particular functions. This improves efficiency of function because different tasks can be shared amongst specialized cells. Energy is saved in not maintaining non-essential organelles in cells that do not require them.
2. (a) **Epithelial tissues:** Single or multiple layers of simple cells forming the lining of internal and external body surfaces. Cells rest on a basement membrane of fibers and collagen and may be specialized. **Note:** epithelial cells may be variously shaped: squamous (flat), cuboidal, columnar etc.
 (b) **Nervous tissue:** Tissue comprising densely packed nerve cells specialized for transmitting electrochemical impulses. Nerve cells may be associated with supportive cells (e.g. Schwann cells), connective tissue, and blood vessels.
 (c) **Muscle tissue:** Dense tissue comprising highly specialized contractile cells called fibers held together by connective tissues.
 (d) **Connective tissues:** Supporting tissue of the body, comprising cells widely dispersed in a semi-fluid matrix (or fluid in the case of blood and lymph).
3. (a) Muscle tissue is made up of long muscle fiber cells and myofibrils which are made up of contractile proteins actin and myosin. These allow the muscle fibers to contract when stimulated. The contraction results in movement of the organism itself (locomotion) or movement of an internal organ.
 (b) Nervous tissue is comprised of two main tissue types, neurons which transmit nerve signals and glial cells which provide support to the neurons. Neurons have several protrusions (dendrites or axons) from their cell body which allow conduction of nerve impulses to target cells.

Plant Tissues (page 129)1. **Collenchyma****Cell type(s):** collenchyma cells**Role:** provides flexible support.**Sclerenchyma****Cell type(s):** sclerenchyma cells**Role:** provides rigid, hard support.**Root Endodermis****Cell type(s):** endodermal cells**Role:** Provides selective barrier regulating the passage of substances from the soil to the vascular tissue.**Pericycle****Cell type(s):** parenchyma cells**Role:** Production of branch roots, synthesis and transport of alkaloids.**Leaf mesophyll****Cell type(s):** spongy mesophyll, palisade mesophyll**Role:** Main photosynthesis site in the plant.**Xylem****Cell type(s):** tracheids, vessel members, fibers, parenchyma cells**Role:** Conducts water and dissolved minerals in vascular plants.**Phloem****Cell type(s):** sieve-tube members, companion cells, parenchyma, fibers, sclereids**Role:** transport of dissolved organic material (including sugars) within vascular plants.**Epidermis****Cell type(s):** epidermal cells, guard cells, subsidiary cells, and epidermal hairs (trichomes).**Role:** Protection against water loss, regulation of gas exchange, secretion, water and mineral absorption.**Root Cell Development** (page 130)

- Cells specialize to take on specific functions.
 - Cells are becoming longer and/or larger.
 - Cells are dividing by mitosis.
- Late anaphase; chromatids are being pulled apart and are at opposite poles.
 - Telophase; there are two new nuclei formed and the cell plate is visible.
 - 25 of 250 cells were in mitosis, therefore mitosis occupies 25/250 or one tenth of the cell cycle.
- The **cambium layer** of cells (lying under the bark between the outer phloem layer of cells and the inner xylem layer of cells). **Note:** Cells dividing from each side of this layer specialize to form new phloem on the outside and new xylem on the inside.

Energy in Cells (page 133)

- Heterotrophs** (strictly chemoheterotrophs) derive energy for biosynthesis from an organic energy source (other living organisms, their dead remains, or their excreted products). **Photosynthetic autotrophs** (photoautotrophs) derive energy for biosynthesis

from light energy (e.g. sunlight) which is the inorganic energy source. **Chemosynthetic autotrophs** (chemoautotrophs) derive energy for biosynthesis from an inorganic chemical energy source (e.g. hydrogen sulfide gas from volcanic vents).

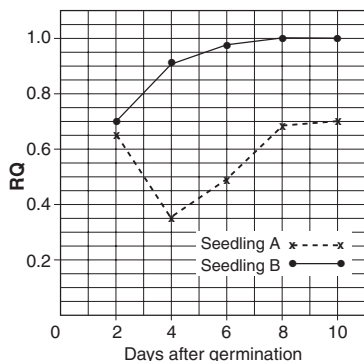
- At this depth there is no sunlight (it is filtered out after several hundred meters). Photosynthetic organisms require a source of sunlight.
 - Hydrogen sulfide
 - They would die due to inability to respire.
 - Chemosynthetic autotrophs (chemoautotrophs)

The Role of ATP in Cells (page 134)

- In the presence of the enzyme ATPase, ATP is hydrolyzed to produce ADP plus a free phosphate, releasing energy in the process.
- Glucose
- Cellular respiration; strictly oxidative phosphorylation
- Solar energy
- Food (gaining nutrient from plants and other animals)
- Like a rechargeable battery, the ADP/ATP system toggles between a high energy state and a low energy. The addition of a phosphate to ADP recharges the molecule so that it can be used for cellular work.
- PHOTOSYNTHESIS**
Starting materials: carbon dioxide, water (as a source of hydrogens), in the presence of light and chlorophyll.
Waste products: oxygen, water.
Role of hydrogen carriers: NADP: Carries hydrogen between light dependent and light independent phases (where the hydrogen is incorporated into sugars).
Role of ATP: Produced in the light dependent phase and used in the light independent phase to make sugars from carbon dioxide and hydrogen.
Overall biological role: Uses light energy to fix carbon into organic molecules which become part of the energy available in food chains.

CELLULAR RESPIRATION**Starting materials:** organic molecules (ultimately glucose), oxygen.**Waste products:** carbon dioxide, water.**Role of hydrogen carriers:** NAD: Carries hydrogens to the electron transport system where their transfer between carriers is coupled to ATP production.**Role of ATP:** A small amount of ATP is used initially to produce pyruvate from glucose. Produced in glycolysis, Krebs cycle, and the ETS.**Overall biological role:** The process by which organisms break down energy rich molecules to release energy in a usable form (ATP).**Measuring Respiration** (page 135)

- RQ at 20°C/48 h = $1.97 \div 2.82 = 0.7$ (0.698)
 - RQ at 20°C/1 h = $2.82 \div 2.82 = 1$. After 2 days without feeding the cricket was metabolizing fats for energy. Shortly (1 hour) after feeding it was metabolizing only carbohydrate (RQ = 1).
- (a) RQ of two seedlings during early germination:



- (b) Both seedlings began their germination metabolizing primarily fats for energy. However, while seedling A continued to metabolize mainly fats (with some synthesis of carbohydrate and organic acids), throughout the 10 day period, seedling B rapidly moved to metabolizing carbohydrate alone. **Note:** The value of 0.91 (seedling B) may have been the result of protein metabolism alone or (more likely) respiration of a mix of fat and glucose.

Cellular Respiration (page 136)

- Glycolysis: cytoplasm
 - Krebs cycle: matrix of mitochondria
 - Electron transport chain: cristae (inner membrane surface) of mitochondria.
- Substrate-level phosphorylation: Formation of ATP by the transfer a phosphate group from a substrate (e.g. a phosphorylated 6C sugar) to ADP directly, with no involvement of an electron transport chain.
 - Oxidative phosphorylation: The process by which glucose is oxidized in a series of redox reactions and the energy released in the electron transfers is coupled to ATP synthesis.

The Biochemistry of Respiration (page 137)

- 6 carbon atoms
 - 3 carbon atoms (glucose split into two)
 - 2 carbon atoms (1 carbon lost as CO_2)
 - 6 carbon atoms (2-carbon acetyl added to 4 carbon)
 - 5 carbon atoms (1 carbon lost as CO_2)
 - 4 carbon atoms (1 carbon lost as CO_2)
- | | |
|-------------------------------|---------|
| (a) Glycolysis: | 2 ATPs |
| (b) Krebs cycle: | 2 ATPs |
| (c) Electron transport chain: | 34 ATPs |
| (d) Total produced: | 38 ATPs |
- Carbon atoms are released as carbon dioxide (CO_2) gas and breathed out through gas exchange surfaces.
- Hydrogen atoms supply energy in the form of high energy electrons. **Note:** These are passed along the respiratory chain, losing energy as they go. The energy released is used to generate ATP.
 - Oxygen is the final electron acceptor at the end of the respiratory chain.
- (a) ATP is generated by **chemiosmosis**.

(b) **In brief:** The synthesis of ATP is coupled to electron transport and movement of hydrogen ions.

In more detail: Energy from the passage of electrons along the chain of electron carriers is used to pump protons (H^+), against their concentration gradient, into the intermembrane space, creating a high concentration of protons there. The protons return across the membrane down a concentration gradient via the enzyme complex, ATP synthetase (also called ATP synthase or ATPase), which synthesizes the ATP.

Anaerobic Pathways (page 139)

- Aerobic respiration** requires the presence of oxygen and produces a lot of useable energy (ATP). **Fermentation** does not require oxygen and uses an alternative H^+ acceptor. There is little useable energy produced (the only ATP generated is via glycolysis).
- $2 \div 38 \times 100 = 5.3\%$ efficiency
 - Only a small amount of the energy of a glucose molecule is released in anaerobic respiration. The remainder stays locked up in the molecule.
- The build up of toxic products (ethanol or lactate) inhibits further metabolic activity.

Photosynthesis (page 140)

- Importance of photosynthesis (a)-(c) in any order:
 - Transforms light energy into chemical energy available to food chains.
 - Creates organic molecules used as building blocks for creating more complex molecules.
 - Releases free oxygen into the atmosphere; oxygen is required by other advanced life forms.
- Water + carbon dioxide $\rightarrow$ glucose + oxygen + water
 - $12\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$
- The glucose end product of photosynthesis can be used as an immediate energy source for cellular respiration (glucose), as a structural component of the plant (as cellulose), or as a stored energy reserve (as starch). Alternatively, the glucose can be converted into other sugars (e.g. fruit sugars or sucrose for translocation around the plant).
- The chloroplast has two distinct regions: the stroma and grana. The light independent reactions (Calvin cycle) take place in the liquid stroma. The light dependent reactions take place in the grana, which comprise stacks of thylakoid membranes containing the chlorophyll pigment molecules.

Pigments and Light Absorption (page 141)

- The absorption spectrum of a pigment is that wavelength of the light spectrum absorbed by a pigment, e.g. chlorophyll absorbs red and blue light and appears green. Represented graphically, the absorption spectrum shows the relative amounts of light absorbed at different wavelengths.
- Accessory pigments absorb light wavelengths that chlorophyll a cannot absorb, and they pass their energy on to chlorophyll a. This broadens the action spectrum

over which chlorophyll a can fuel photosynthesis.

Photosynthetic Rate (page 142)

- Photosynthetic rate increases rapidly then levels off.
 - Up to a certain light intensity more light is available to the chlorophyll so the rate increases. When all the chlorophyll molecules are activated (saturated) by the light, more light has no further effect.
- Increased temperature increases the photosynthetic rate, but this effect is not marked at low CO_2 .
 - At higher temperature biochemical reactions occur more rapidly. At low CO_2 levels, rate is determined more by the CO_2 (raw material) available (rates are low regardless of temperature).
- The photosynthetic rate is determined by the rate at which CO_2 enters the leaf. When this declines because of low atmospheric levels, so does photosynthetic rate.
- By changing only one factor at a time (either temperature or CO_2 level) it is possible to assess the effects of each one separately.
 - CO_2 has the greatest effect of these two variables.
 - At low levels of CO_2 , increase in temperature has little effect (the rate of CO_2 entry into the leaf is the greatest determinant of photosynthetic rate).

The Biochemistry of Photosynthesis (page 143)

- NADP:** Carries H_2 from the light dependent phase to the light independent reactions.
- Chlorophyll:** These pigment molecules trap light energy and produce high energy electrons. These are used to make ATP and NADPH. The chlorophyll molecules also split water, releasing H^+ for use in the light independent reactions and liberating free O_2 .
- 5C
 - 3C (X2 molecules)
 - 3C
 - 5C
- Light dependent (D) phase:** Takes place in the grana (thylakoid membranes) of the chloroplast and requires light energy to proceed. The light dependent phase generates ATP and reducing power in the form of NADPH. The electrons and hydrogen ions come from the splitting of water.
 - Calvin cycle:** Takes place in the stroma of the chloroplast and does not require light energy to proceed. The Calvin cycle uses ATP and NADPH from the light dependent phase, for the step-wise reduction of carbon dioxide to glucose.
- Carbon and oxygen from carbon dioxide gas (via stomata). Hydrogen from water (via the roots and vascular system) obtained from the soil. **Note:** It has been shown through oxygen isotope studies that the free oxygen produced as a result of photosynthesis comes from water and the oxygen in the carbohydrate comes from carbon dioxide.
- The ATP synthesis is coupled to electron transport. When the light strikes the chlorophyll molecules, high energy electrons are released by the chlorophyll molecules. The energy lost when the electrons are passed through a series of electron carriers is used to bond a phosphate to ADP to make ATP.

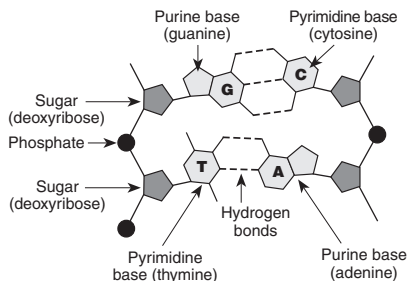
Note: ATP is generated (in photosynthesis and cellular respiration) by **chemiosmosis**. As the electron carriers pick up the electrons, protons (H^+) pass into the space inside the thylakoid, creating a high concentration of protons there. The protons return across the thylakoid membrane down a concentration gradient via the enzyme complex, ATP synthetase that synthesizes the ATP (also called ATP synthase or ATPase).

- Non-cyclic (photo)phosphorylation:** Generation of ATP using light energy during photosynthesis. The electrons lost during this process are replaced by the splitting of water.
 - The term non-cyclic **photophosphorylation** is also (commonly) used because it indicates that the energy for the phosphorylation is coming from light.
 - In oxidative phosphorylation, the energy for the phosphorylation comes from the oxidation of glucose (the transfer of electrons released in the oxidation is coupled to ATP synthesis).
- In cyclic photophosphorylation, the electrons lost from photosystem II are replaced by those from photosystem I rather than from the splitting of water. ATP is generated in this process, but not NADPH. **Note:** In the cell, both cyclic and non-cyclic photophosphorylation operate to different degrees in order to keep the production of NADPH and ATP balanced.

Note: In the next activities, including that on transcription, the **accepted convention** amongst molecular geneticists has been used, i.e. the **coding** (sense or non-transcribed) strand contains the **same base sequence as the mRNA** that is transcribed from the **template** (antisense) **strand**. This terminology arises from the fact of where the gene (to be transcribed) is located (the "coding" strand). This may oppose what appears in some texts, where there is much confusion in the use of these terms. In fact, with the exception of template strand, the modern view (and the view in the more authoritative, current texts) is to avoid the use of these terms, as they imply that one strand alone always carries the genes.

Nucleic Acids (page 147)

- Labels as follows (only half of the section of DNA illustrated in the workbook is shown):



- The following bases always pair in a normal double strand of DNA: guanine with cytosine, cytosine with guanine, thymine with adenine, adenine with thymine.
 - In mRNA, uracil replaces thymine in pairing with adenine.

- (c) The hydrogen bonds in double stranded DNA hold the two DNA strands together.
3. **Nucleotides** are building blocks of nucleic acids (DNA, RNA). Their precise sequence provides the genetic blueprint for the organism.
4. The template strand of DNA is complementary to the coding strand and provides the template for the transcription of the mRNA molecule. The coding strand has the same nucleotide sequence as the mRNA (it carries the code), except that thymine in the coding strand substitutes for uracil in the mRNA.
- 5.
- | | DNA | RNA |
|--------------------------|---|--|
| Sugar present | Deoxyribose | Ribose |
| Bases present | Adenine
Guanine
Cytosine
Thymine | Adenine
Guanine
Cytosine
Uracil |
| Number of strands | Two (double) | One (single) |
| Relative length | Long | Short |

DNA Molecules (page 149)

1. (a) 95 times more base pairs
(b) 630 times more base pairs
2. < 2% encodes proteins or structural RNA.
3. (a) and (b) in any order:
(a) Much of the once considered 'junk DNA' has now been found to give rise to functional RNA molecules (many with regulatory functions).
(b) Complex organisms contain much more of this non-protein-coding DNA which suggests that these sequences contain RNA-only 'hidden' genes that have been conserved through evolution and have a definite role in the development of the organism.

The Genetic Code (page 150)

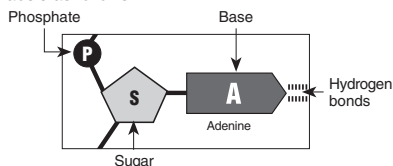
1. This exercise demonstrates the need for a 3-nucleotide sequence for each codon and the 'degeneracy' in the genetic code.

Amino acid	Codons	No
Alanine	GCU GCC GCA GCG	4
Arginine	CGU CGC CGA CGG AGA AGG	6
Asparagine	AAU AAC	2
Aspartic Acid	GAU GAC	2
Cysteine	UGU UGC	2
Glutamine	CAA CAG	2
Glutamic Acid	GAA GAG	2
Glycine	GGU GGC GGA GGG	4
Histidine	CAU CAC	2
Isoleucine	AUU AUC AUA	3
Leucine	UAA UUG CUU CUC CUA CUG	6
Lysine	AAA AAG	2
Methionine	AUG	1
Phenylalanine	UUU UUC	2
Proline	CCU CCC CCA CCG	4
Serine	UCU UCC UCA UCG AGU AGC	6
Threonine	ACU ACC ACA ACG	4
Tryptophan	UGG	1
Tyrosine	UAU UAC	2
Valine	GUU GUC GUA GUG	4

2. (a) 16 amino acids
(b) Two-base codons (e.g. AT, GG, CG, TC, CA) do not give enough combinations with the 4-base alphabet (A, T, G and C) to code for the 20 amino acids.
3. Many of the codons for a single amino acid vary in the last base only. This would reduce the effect of point mutations; only some changes would create new and potentially harmful amino acid sequences. **Note:** Only 61 codons are displayed above. The remaining 3 are **terminator** codons (labeled 'STOP' codons in the table in the workbook). These are considered the 'punctuation' or controlling codons that mark the end of a gene sequence. The amino acid **methionine** (AUG) is regarded as the 'start' (initiator) codon.

Creating a DNA Model (page 151)

3. Labels as follows:



4. & 5. See the next page.
6. Factors preventing a mismatch of nucleotides:
- (a) The number of hydrogen bond attraction points.
(b) The size (length) of the base (thymine and cytosine are short, adenine and guanine are long).
- Examples:
- Cytosine will not match guanine because the bases are too far apart.
 - Guanine will not match thymine because they are too long to fit side-by-side.
 - Thymine will not match adenine because there is a mis-match in the number and orientation of H bonds.

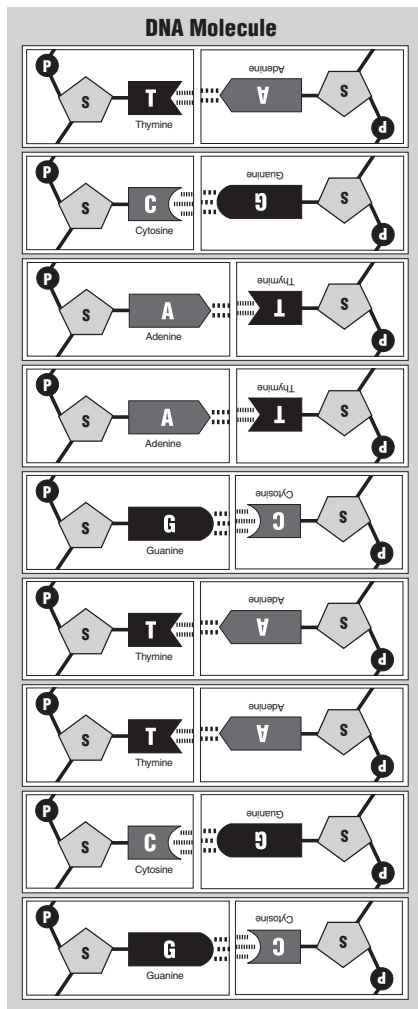
DNA Replication (page 155)

1. DNA replication prepares a chromosome for cell division by producing two chromatids which are (or should be) identical copies of the genetic information for the chromosome.
2. (a) Step 1: Enzymes unwind DNA molecule to expose the two original strands.
(b) Step 2: DNA polymerase enzyme uses the two original strands as templates to make complementary strands.
(c) Step 3: The two resulting double-helix molecules coil up to form two chromatids in the chromosome.
3. (a) Helicase: Unwinds the 'parental' strands.
(b) DNA polymerase I: Hydrolyzes the RNA primer and replaces it with DNA.
(c) DNA polymerase III: Elongates the leading strand. It synthesizes the new Okazaki fragment until it encounters the primer on the previous fragment.
(d) Ligase: Joins Okazaki fragments into a continuous length of DNA.
4. 16 minutes 40 seconds
4 million nucleotides replicated at the rate of 4000 per

second: $4\,000\,000 \div 4000 = 1000$ s
 Convert to minutes = $1000 \div 60 = 16.67$ minutes
 (Note that, under ideal conditions, most of a bacteria's cell cycle is spent in cell division).

Creating a DNA molecule continued

4. & 5.



The Simplest Case: Genes to Proteins (page 157)

- This exercise shows the way in which DNA codes for proteins. Nucleotide has no direct protein equivalent.
 - Triplet codes for amino acid.
 - Gene codes for polypeptide chain (may be a

polypeptide, protein, or RNA product).

(c) Transcription unit codes for functional protein.

- Nucleotides** are made up of: phosphate, sugar, and one of four bases (adenine, guanine, cytosine, and thymine or uracil).
 - Triplet** is made up of three consecutive nucleotide bases that are read together as a code.
 - Gene** comprises a sequence of triplets, starting with a start code and ending with a termination code.
 - Transcription unit** is made up of two or more genes that together code for a functional protein.
- Steps in making a functional protein:
 - The template strand is made from the DNA coding strand and is transcribed into mRNA.
 - The code on the mRNA is translated into a sequence of amino acids, which are linked with peptide bonds to form a polypeptide chain (this may be a functional protein in its own right).
 - The proteins coded by two or more genes come together to form the final functional protein.

Analyzing a DNA Sample (page 158)

- Use the *mRNA* table on the page: **The Genetic Code** in the workbook to determine the amino acid sequence.

Synthesized DNA CGT AAG TAC TTG ATC AGA
 GCT CTT CGA AAA TCG

DNA sample: GCA TTC ATG AAC TAG TCT
 CGA GAA GCT TTT AGC

mRNA: CGU AAG UAC UUG AUC AGA
 GCU CUU CGA AAA UCG

Amino acids: Arg Lys Tyr Leu Iso Arg
 Ala Leu Arg Lys Ser

- ATG ATC GGC GCT AAA TGT TAA
 - ATG CGG AAT TTC CCG GCT TAG
 - DNA replication
- mRNA: AUG AUC GGC GCU AAA UGU UAA
 Amino acids: Met Iso Gly Ala Lys Cys STOP
 - mRNA: AUG CGG AAU UUC CCG GCU UAG
 Amino acids: Met Arg Asn Phe Pro Ala STOP
 - Protein synthesis

Gene Expression (page 159)

- In **prokaryotic** gene expression, RNA is translated into protein almost as fast as it is transcribed; there is no nucleus therefore no separation of the transcription and translation processes. The presence of introns in a prokaryotic genome would interfere with protein function because there would be no time between transcription and translation to splice them out. In contrast, **eukaryotic** gene expression involves production of a primary RNA transcript from which the introns are removed. There is sufficient time for this to take place because transcription and translation occur inside and outside the nucleus respectively. **Note:** Evidence in support of this: Prokaryote DNA consists almost entirely of protein-coding genes and their regulatory sequences with very little non-protein coding DNA. Eukaryotic DNA comprises large amounts of non-protein coding sequences, much of which we now know

codes for functional (regulatory) RNAs.

- In the new view of eukaryotic gene expression, the so-called "junk DNA", traditionally regarded as non-functional, is considered to play a necessary role in the eukaryote cell. In fact, there is a good correlation between the amount of non-protein coding DNA a species has and its complexity. Although this DNA does not code for proteins, it does code for RNA molecules with regulatory functions (some of these involving regulation of the genome itself). What's more, in the new view of gene expression, not all of the exonic RNA is translated into protein; some contributes to regulatory microRNAs. In the old view, all exonic RNA was thought to code for proteins.
- The one gene-one protein model is still appropriate for prokaryotes because, in the absence of introns, RNA transcripts are translated directly into proteins. Because of the small size of prokaryotic genomes and their one site of protein synthesis, there is very little non-protein coding DNA present.

Transcription (page 161)

- mRNA carries a copy of the genetic instructions from the DNA in the nucleus to ribosomes in the cytoplasm. The rate of protein synthesis can be increased by making many copies of identical mRNA from the same piece of DNA.
- (a) AUG
(b) UAA, UAG, UGA
- (a) AUG AUC GGC GCU AAA
(b) AUG UUC GGA UAU UUU

Translation (page 162)

- AUG AUC GGC GCU AAA
- (a) 61
(b) There are 64 possible codons for mRNA, but three are terminator codons. 61 codons for mRNA require 61 tRNAs each with a complementary codon.

Protein Synthesis Review (page 163)

- Process 1: Unwinding the DNA molecule.
 - Process 2: mRNA synthesis, nucleotides added to the growing strand of messenger RNA molecule.
 - Process 3: DNA rewinds into double helix structure.
 - Process 4: mRNA moves through nuclear pore in nuclear membrane to the cytoplasm.
 - Process 5: tRNA molecule brings in the correct amino acid to the ribosome.
 - Process 6: Anti-codon on the tRNA matches with the correct codon on the mRNA and drops off the amino acid.
 - Process 7: tRNA leaves the ribosome.
 - Process 8: tRNA molecule is 'recharged' with another amino acid of the same type, ready to take part in protein synthesis.
- A: DNA
 - B: Free nucleotides
 - C: RNA polymerase
 - D: mRNA
 - E: Nuclear membrane
 - F: Nuclear pore
 - G: tRNA
 - H: Amino acids
 - I: Ribosome
 - J: Polypeptide chain

- Factors determining whether or not a protein is produced (in any order):
 - Whether or not the protein is required by the cell (regulated by control of gene expression).
 - Whether or not there is an adequate pool of the amino acids and tRNAs required for the particular protein in question.

Gene Control in Eukaryotes (page 164)

- Promoter:** A DNA sequence where RNA polymerase binds and starts transcription.
 - Transcription factors:** These are proteins that recognize and bind to the promoter sequence and to the enhancer sequence and thereby facilitate initiation of transcription.
 - Enhancer sequence:** The DNA sequence to which the transcription factors called activators bind. This binding is important in bringing the activators in contact with the transcription factors bound to the RNA polymerase at the promoter.
 - RNA polymerase:** The enzyme that, with the initial aid of transcription factors, transcribes the gene.
 - Terminator sequence:** Nucleotide sequences at the end of a gene that function to stop transcription.
- Difference between gene control in prokaryotes and eukaryotes (any one of):
 - Eukaryotic genes are not found as operons; the control sequences may be some distance from the gene to be transcribed.
 - In eukaryotic gene expression, the transcription factors are important; only when the transcription factors are assembled can the gene be transcribed.
 - Eukaryotic gene expression involves the formation of hairpin loop in the DNA which brings the transcription factors and polymerase into contact.

Gene Control in Prokaryotes (page 165)

- Operon:** Consists of at least one structural gene coding for the primary enzyme structure, and two regulatory elements: the operator and the promoter.
 - Regulator gene** (repressor gene): Produces a repressor substance that binds to the operator, preventing transcription of the structural genes.
 - Operator:** This is a non-coding sequence of DNA that is the binding site for the repressor molecule.
 - Promoter:** Site of RNA polymerase binding to start the transcription process.
 - Structural genes:** Genes responsible for producing enzymes that control the metabolic pathway.
- In an inducible enzyme system, the enzymes required for the metabolism of a particular substrate are produced only when the substrate is present. This saves the cell valuable energy in not producing enzymes that have no immediate use.
 - Inducible enzyme systems are not adaptive when the substrate is present all (or most) of the time.
 - Regulation of a non-inducible system is achieved (in prokaryotes) through **gene repression**: the structural genes are normally transcribed all the time and, when the end product (e.g. tryptophan in *E. coli*) is present in excess to requirements, the genes are switched off.
- In the inducible system, the genes for metabolizing the substrate are usually switched off, but are switched on

when the substrate is present. In the gene repression model, the genes (for metabolizing the substrate) are normally switched on and are only switched off when the substrate is present in excess.

Control of Metabolic Pathways (page 167)

1. A **metabolic pathway** is simply a series of related chemical reactions that converts one compound to another in a sequence of steps. Each step in a metabolic pathway is controlled by enzymes; the end product of one enzyme-controlled step provides the substrate for the next step. In the metabolism of the amino acid phenylalanine, an enzyme controls the conversion of phenylalanine to tyrosine. Enzyme controlled steps lead to thyroxine (a hormone), to melanin, or to any of a series of intermediate breakdown products. Failure of enzymes in any of these many steps leads to clearly defined metabolic disorders of varying severity.
2. Any three of: thyroxine, melanin, carbon dioxide, water
3. (a) Tyrosinase
(b) Phenylalanine hydroxylase
(c) Hydroxyphenylpyruvic acid oxidase
(d) Homogentisic acid oxidase
4. People with PKU have low levels of tyrosine, the raw material for making melanin (the pigment that gives dark color to the skin and hair). Tyrosine is normally created from phenylalanine by an enzyme, which is faulty in this case.
5. Disorders in tyrosine metabolism can lead to cretinism or albinism. Cretinism is the result of errors in the metabolic pathway to thyroxine, an important growth hormone for the development of body organs. The lack of thyroxine results in the symptoms of cretinism: small body size (dwarfism), mental retardation, and undeveloped sexual organs. Albinism is the result of malfunctions of the enzyme tyrosinase, which converts tyrosine to the pigment melanin. Lack of melanin results in the symptoms of albinism: a total lack of pigmentation in the skin, eyes, and hair.
6. (a) Lack of melanin.
(b) Excess phenylpyruvic acid.
(c) Lack of thyroxine.
(d) Excess hydroxyphenylpyruvic acid.
(e) Excess homogentisic acid.
7. You would take a blood sample and test for excessive amounts of phenylpyruvic acid (in fact, this is a routine blood test performed five days after birth).
8. (a) Chemicals present in excess: Precursor
(b) Chemicals absent: Intermediate, end product

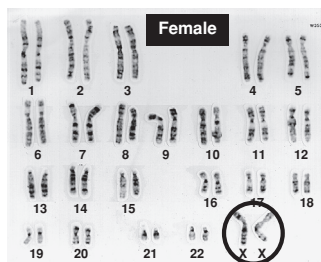
Eukaryote Chromosome Structure (page 171)

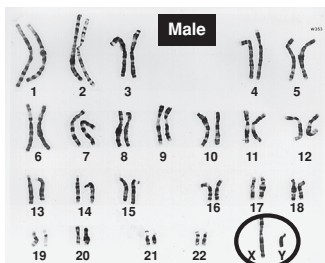
1. (a) **DNA**: A long, complex nucleic acid molecule found in the chromosomes of nearly all organisms (some viruses have RNA instead). Provides the genetic instructions (genes) for the production of proteins and other gene products (e.g. RNAs).
(b) **Chromatin**: Chromosomal material consisting of DNA, RNA, and histone and non-histone proteins. The term is used in reference to chromosomes in the non-condensed state.

- (c) **Histone**: Simple proteins that bind to DNA and help it to coil up during cell division. Histones are also involved in regulating DNA function in some way.
 - (d) **Centromere**: A bump or constriction along the length of a chromosome to which spindle fibers attach during cell division. The centromere binds two chromatids together.
 - (e) **Chromatid**: One of a pair of duplicated chromosomes produced prior to cell division, joined at the centromere. The terms chromatid and chromosome distinguish duplicated chromosomes before and after division of the centromere.
2. The chromatin (DNA and associated proteins) combine to coil up the DNA into a "super coiled" arrangement. The coiling of the DNA occurs at several levels. The DNA molecule is wrapped around bead-like cores of (8) histone proteins (called nucleosomes), which are separated from each other by linker DNA sequences of about 50 bp. The histones (H1) are responsible for pulling nucleosomes together to form a 30 nm fiber. The chromatin fiber is then folded and wrapped so that it is held in a tight configuration. The different levels of coiling enables a huge amount of DNA to be packed, without tangling, into a very small space in a well organized, orderly fashion.

Karyotypes (page 173)

1. A **karyotype** is the chromosome complement of a cell or organism, characterized by the number, size, shape, and centromere position of the chromosomes. It can provide information on gender and chromosomal abnormalities, such as Down syndrome.
2. **Autosomes** are the non-sex chromosomes that occur as 'matching' homologous pairs and are not involved in determining the sex of the organism. In contrast, the **sex chromosomes** (also called heterosomes) are the pair of chromosomes (XX in female humans and XY in male humans) that determine gender.
3. Number the chromosomes: See next page.
4. Circle the sex chromosomes: See next page.
5. (a) Female autosomes: 44, sex chromosomes: XX
(b) Male autosomes: 44, sex chromosomes: XY
6. (a) 46 (b) 23





Prenatal Diagnosis (page 175)

- (a) An ultrasound scan might be used to determine the correct age of a fetus, to check that growth is proceeding normally, to determine the position of the fetus and/or placenta, to detect major fetal abnormalities such as spina bifida, or to diagnose a multiple pregnancy (twins).
(b) It is often possible to tell the sex of the baby and to determine conception date. **Note:** It is also possible to detect forming cysts or cancers (e.g. ovarian).
(c) Ultrasound scans are performed relatively late in pregnancy (about half-way through) because, by then, the limbs and body organs are well formed and accurate measurements of body parts can be taken. **Note:** Before about 22 weeks, rates of fetal development are fairly uniform, but after that individual differences become apparent and it is more difficult to determine fetal age from size.
- CVS might be carried out very early where there is an expected higher risk of a genetic (chromosomal) abnormality (because the mother is older or either parent carries a heritable genetic defect). The parents then know the probable outcome of the pregnancy and prepare themselves appropriately for it.
- Some of the disorders that can be detected through amniocentesis are (any one of): hemophilias, Down syndrome, muscular dystrophy, Tay-Sach's disease, some forms of leukemia, Klinefelter and Turner syndromes, sickle-cell disease, thalassemias, and cystic fibrosis.
- (a) Before age 35, the risk of miscarriage from the amniocentesis procedure is higher than the risk of carrying a child with a chromosome abnormality.
(b) Amniocentesis may be recommended in younger women where there is family history of inherited disorders or a history of miscarriage.
- (a) and (b) any one of the following:
 - Family history of inherited genetic disorders.
 - History of infertility, miscarriage, stillbirth, or early neonatal death.
 - First pregnancy at an older age or age over 38.
- Chromosome abnormalities are often fatal and are aborted naturally before reaching term (full development). Recurrent miscarriages may indicate that an inherited genetic defect is causing problems.
- (a) Gender determination opens up the possibility for gender choice and the termination of pregnancies where the child is of an unwanted sex. In the long

term (as in China) this can lead to a skewing of normal gender ratios in the adult population.

- (b) Parents may choose to abort a fetus that is viable if it has any kind of defect. This raises concerns about our right to give or take life. Some parents may wish to terminate a pregnancy even if a defect is treatable in life (e.g. deafness, heart defects etc.).

Human Karyotype Exercise (page 177)

By studying the distinguishing characteristics of the chromosomes, you should be able to arrange the them in their correct sequence on the karyotype record sheet.

- The karyotype should be organized as for the "Typical layout of a human karyotype" on page 169, but it has **one extra chromosome number 18 (trisomy 18)**, and is **female (XX)** rather than male (XY). **Note:** Students will find out later that this genotype is Edward syndrome (an autosomal trisomy, less common than Down syndrome).
- (a) Sex: female
(b) Abnormal
(c) 45 + XX (trisomy 18 or Edward syndrome)

Genomes (page 180)

- The **genome** of an organism is a complete haploid set of all chromosomes (i.e. all the genetic material carried by a single representative of each of all chromosome pairs).
- (a) 5375 bases (b) 5.375 kb (c) 0.005375 Mb
- 1542 bases
- It is a comparatively small genome, others having 10 to 40 times as much genetic material (e.g. 48.6-190 kb).

Sources of Genetic Variation (page 181)

- (a) Meiosis provides an assortment of different gametes as a result of independent assortment.
(b) Crossing over in meiosis exchanges parts of chromosomes and results in genes to be swapped on chromosome pairs.
(c) Mate selection will bring together the genes of two different individuals.
- The environment can alter the phenotype by altering the basic expression of a trait. Examples include: trees that are grown at high altitude are stunted in growth, trees exposed to a strong prevailing wind appear distorted in shape (windswept), poor nutrition in infancy can retard brain and bone development.
- (a)-(c) any three in any order:
 - Tanning the skin to look brown-skinned.
 - Dieting to lose weight.
 - Exercising to increase fitness or build muscle mass.
 - Cosmetic surgery, e.g. rhinoplasty, and dentistry, e.g. tooth whitening, to improve appearance.
- Siblings share many identical genes (from their parents) with their brothers and sisters. However, as a result of crossing over and random assortment of maternal and paternal chromosomes into the gametes, there are enough genetic differences between them to make them appear different.

5. (a) A **neutral** mutation is one that has no harmful or beneficial effect under the current conditions.
 (b) While a neutral mutation may not have an effect initially, in the future it may disadvantage or benefit the individual that possesses it. Such a change may confer a selective disadvantage or advantage (with respect to survival or reproduction) to that individual in the prevailing environment.

Gene-Environment Interactions (page 183)

- The **genotype** is the genetic constitution of an organism, as opposed to the **phenotype**, which is the organism's physical appearance. For example, the incubation temperature of fertilized eggs determines the type of sexual development in some animal species such as turtles.
- Physical factors: wind speed, temperature, air density, water availability.
- The acidity of the soil. In alkaline soils they are pink or red-purple, in acid soil the flowers are blue. The color is due to the presence or absence of aluminum compounds in the flowers, and aluminum in the soil is only accessible to plants when soil pH is low. When aluminum is present within the plant, the flowers are blue. When the aluminum is absent, the flowers are pink. **Note:** Growers may apply aluminum sulfate to the soil to lower the pH and produce blue flowers. Adding lime produces pink flowers.
- These are the cooler parts of the body. Body heat is lost from these areas which make it cool enough for the enzyme responsible for color-pointing to remain active.
- To ensure genetic potential is reached, provide the optimum growth conditions for that plant, e.g. suitable water availability (water regularly), adequate nutrient supply (fertilizer application), sufficient sunlight (keep out of shade), equable temperature (warmth, protect from frost and wind), protection from pests and diseases (companion plant or spray for pests).
- (a) A **cline** is a continuous, or nearly continuous, gradation in a phenotypic character within a species, associated with a change in an environmental variable such as temperature or wind.
 (b) **Plant A:** The observed phenotype (prostrate) of this species is not due to genetic factors, but to the effect of climate on growth patterns. In the absence of a harsh environment, the plant reverts to its normal growing habit.
Plant B: The low growing phenotype of this species is controlled by genes (not environmental factors).
 (c) Plant A is most likely to show clinal variation.

Meiosis (page 185)

- In the first division of meiosis, homologous pairs of chromosomes pair to form bivalents. Segments of chromosomes may be exchanged in crossing over and the homologues then separate (are pulled apart). This division reduces the number of chromosomes in the intermediate cells, so that only one chromosome from each homologous pair is present.
- In the second division of meiosis, chromatids separate (are pulled apart), but the number of chromosomes

stays the same. This is more or less a 'mitotic' division.

- Mitosis involves a division of the chromatids into two new daughter cells thus maintaining the original number of chromosomes in the parent cell. Meiosis involves a division of the homologous pairs of chromosomes into two intermediary daughter cells thus reducing the diploid number by half. The second stage of meiosis is similar to a mitotic division, but the haploid number is maintained because the chromatids separate.
- A shows metaphase of meiosis I; the homologous pairs of chromosomes are lined up on the cell equator. B shows metaphase of meiosis II; the individual chromatids are about to separate.

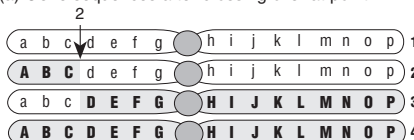
Crossing Over (page 187)

- Unexpected combinations of alleles for genes will occur that would not normally be present in gametes.
- Crossing over provides one source of genetic variation amongst individuals in a population. This is important for providing the raw material upon which natural selection acts.

Crossing Over Problems (page 188)

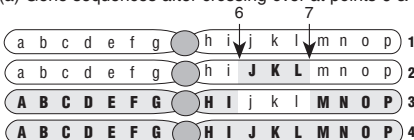
Note that each of the problems is independent of the other problems (i.e. they are not a sequence).

- (a) Gene sequences after crossing over at point 2:



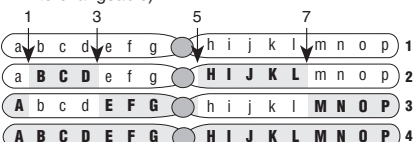
(b) A, B and C

- (a) Gene sequences after crossing over at points 6 & 7:



(b) J, K and L

- (a) Gene sequences after crossing over at points 1, 3, 5, and 7. (Note that results for chromatids 2 & 3 are interchangeable):



(b) B, C, D and H, I, J, K, L

- Crossing over increases the amount of mixing of genes to produce new combinations in the offspring. It counteracts the effect of gene linkage and increases variation in the gene pool.

Linkage (page 189)

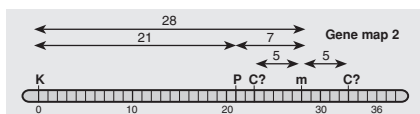
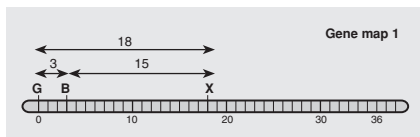
1. **Linkage** refers to the situation where genes are located on the same chromosome. As a result, they tend to be inherited together as a unit.
2. (a) AaBb, Aabb, aaBb, aabb
(b) F₁ genotype: all CucuEbeb (heterozygotes)
F₁ phenotype: all wild type (straight wing, gray body).
3. Gene linkage reduces the amount of variation because the linked genes are inherited together and fewer genetic combinations of their alleles are possible.

Recombination (page 190)

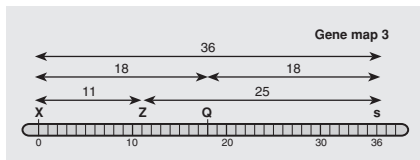
1. **Recombination** refers to the exchange of alleles between homologous chromosomes as a result of crossing over. It produces new associations of alleles in the offspring.
2. Recombination increases the amount of genetic variation because parental linkage groups separate and new associations of alleles are formed in the offspring. The offspring show new combinations of characters that are unlike the parental type.
3. A greater than 50% recombination frequency indicates that there is independent assortment (the genes must be on separate chromosomes).

Chromosome Mapping (page 191)

1. See below.



We do not know the map distance between P and C, so gene C could be at one of the two positions indicated.



2. (a) VgvgEbeb: normal wing, gray body
vgvgEbeb: vestigial wing, ebony body
Vgvgbeb: normal wing, ebony body
vgvgbeb: vestigial wing, ebony body
(b) Crossover frequency: recombinants ÷ total x 100
 $217 \div 1268 \times 100 = 17.1\%$

3. (a) The study of non-human genomes will provide the basis for comparative studies that are critical to the understanding of more complex systems. Model organisms (e.g. yeast, mouse) also offer a cost effective way to follow the inheritance of genes through many generations in a relatively short time. Some of the organisms for which gene maps have been completed are important in an industrial (commercial) or medical (e.g. pathogenic) sense.
- (b) The HGP will provide the information needed to understand the structure, organization, and function of DNA in chromosomes. Genes involved in genetic diseases will be found, and further studies will lead to an understanding of how those genes contribute to disease. **Note:** In this light, the emphasis in medicine should shift to a preventative rather than treatment approach. For example, corrective treatment for metabolic disorders using gene therapy, and implementation of screening procedures for those with heritable diseases, or for those who can take preventative measures against the development of a disease (e.g. diabetes). A knowledge of racial differences in genetic makeup will also help to determine why some races are more susceptible to certain diseases than others. This should help improve preventative treatments for those at risk.

Mutagens (page 193)

1. A **mutagen** is any physical or chemical agent that increases the frequency of mutation (change or disruption in DNA) above the spontaneous (background) rate. Many mutagens are also **carcinogens**, in that the changes they cause to the DNA trigger the development of malignant tumors or cancers. Mutagens bring about their effects by disrupting the base sequence of genes, which can affect that gene's product. Mutations to regulatory genes, such as those controlling cell division, are among the most damaging.

The Effect of Mutations (page 194)

1. A mutation is any alteration in the base sequence of DNA. The effect of this is the production of a new protein (or other gene product) or the failure to produce a protein. When the mutation involves a change to a regulatory gene (e.g. for production of an enzyme or transcription factor), the consequences can be far-reaching and devastating, because the functions dependent on that regulatory protein also fail.
2. **Somatic mutations** occur in the body (non-gametic or somatic) cells and are not inherited. They may affect an individual within its lifetime. **Gametic mutations** may be inherited and can therefore affect descendants.
3. The mutation does not extend to the seeds (the gametic portion which will be inherited).
4. Organisms such as these have short generation times, so the cumulative effects of mutations over several generations can be feasibly studied. In addition, (especially in bacteria) mutation rates are high and mutations can be induced easily.

For Harm or Benefit? (page 195)

- (a) A neutral mutation has no effect on the survival and reproduction (fitness) of the individual, whereas a beneficial mutation confers a selective advantage in terms of fitness and a harmful mutation has a deleterious effect on fitness. Effects apply in the prevailing environment.
 - (b) Harmful mutations are the most common, because changes in the normal genetic make-up of an individual are more likely to have a deleterious effect (and cause errors) than to be fortuitously beneficial or neutral.
- It allows people with the mutation to eat food high in cholesterol but not suffer from atherosclerosis.

Antibiotic Resistance (page 196)

- Spontaneous resistance can occur in a bacterium as a result of a mutation caused by exposure to radiation or mutagenic chemicals, or through transcription error. The mutated gene then codes for antibiotic resistance.
- When we interfere with microbial survival by using antibiotics, we inadvertently select for antibiotic resistant mutants. Patients assist this process when they fail to complete a course of antibiotics and do not kill all the targeted microbes in their system. When the antibiotic level (in their body) decreases, some resistant bacteria survive and reproduce. Patients may also use antibiotics unnecessarily (e.g. for viral infections), exposing bacteria in their system to the antibiotic and providing the opportunity for resistance to develop.

Gene Mutations (page 197)

- A **reading frame shift** occurs when the sequence of bases is offset by one position (by adding or deleting a base). This alters the order in which the bases are grouped as triplets and can severely alter the amino acid sequence.
- (a) Reading frame shifts and nonsense substitutions.
(b) They may cause large scale disruption of the coded instructions for making a protein. Either a completely wrong amino acid sequence for part of the protein or a protein that is partly completed (missing amino acids due to an out-of-place terminator codon).
- Because a reading frame shift severely affects the basic construction of a protein as a set sequence of amino acids, it is unlikely that the protein will be able to carry out its designated role (structural, catalytic, transport). It will lose its biological activity (functionality).

Examples of Gene Mutations (page 199)

- (b) *Gene name:* HBB *Chromosome:* 11
Mutation type: autosomal recessive. *May be caused by base deletion, base insertion, or gene deletion (severity depends on the mutation).
- (c) *Gene name:* CFTR *Chromosome:* 7
Mutation type: autosomal recessive. Great range: deletion, missense, nonsense, misplaced terminator codon. Most common is a deletion of 3 nucleotides.
- (d) *Gene name:* IT15 *Chromosome:* 4
Mutation type: autosomal dominant. Duplication (CAG repeats of varying length).

- Few or no β chains causes severe anemia. Frequent blood transfusions are required and this can cause iron accumulation in the tissues and organs.
- Mutations would have arisen in an individual and spread out gradually from that origin. Thus certain genetic disorders tend to have a higher occurrence in certain regions, especially where the population tends to have stayed relatively isolated geographically.

Cystic Fibrosis Mutation (page 200)

- (a) mRNA: GGC ACC AUU AAA GAA AAU AUC AUC UUU GGU GGU
(b) Amino acids: Gly Thr Iso Lys Glu Asn Iso Iso Phe Gly Gly
- (a) Mutant mRNA: GGC ACC AUU AAA GAA AAU AUC AUC I GGU GGU
(b) Type of mutation: Triplet deletion.
(c) Amino acids coded by mutant DNA: Gly Thr Iso Lys Glu Asn Iso Iso I Gly Gly
(d) Amino acid missing: Phenylalanine (Phe).
- CF has varying degrees of severity because there are more than 500 mutations of the CF gene. The resulting mutant CFTR protein may not function at all, or it may function only in part, producing a system that is variously effective.

Sickle Cell Mutation (page 201)

- (a) Bases: 21
(b) Triplets: 7
(c) Amino acids coded for: 7
- mRNA: GUG CAC CUG ACU CCU GAG GAG
- Amino acids: Val His Leu Thr Pro Glu Glu
- Mutant DNA: CAC GTG GAC TGA GGA CAC CTC
Type of mutation: Substitution
- Mutant mRNA: GUG CAC CUG ACU CCU GUG GAG
- Amino acids coded by mutant DNA:
Val His Leu Thr Pro Val Glu
- A base substitution causes a change in one amino acid in the hemoglobin molecule. The mutated hemoglobin, being less soluble, causes a distortion of the red blood cells and results in various severe circulatory problems.

Chromosome Mutations (page 202)

- (b) **Original:** ABCDEFGHNMNOPQRST
Mutated: ABFEDCGHNMNOPQRST
(c) **Original:** 1234567890
ABCDEFGHIHNMNOPQRST
Mutated: ABCDEF1234567890
GHNMNOPQRST
(d) **Original:** ABCDEFMNOPQ
ABCDEFMNOPQ
Mutated: ABCDEABCFMNOPQ
FMNOPQ
- Inversion, since there is no immediate potential loss of genes from the chromosome. **Note:** At a later time, inverted genes may be lost from a chromosome during

crossing over, due to unequal exchange of segments.

The Fate of Conceptions (page 203)

1. The **maternal age effect** refers to the higher probability of chromosomal disorders in the offspring of older mothers. It is pronounced in the common autosomal trisomies; the chance of producing a child with a trisomic disorder is very low through the early reproductive years (20-35), but increases rapidly after age 40 until the end of a woman's reproductive life (around 50 years).
2. **Amniocentesis** involves extracting a sample of amniotic fluid from the uterus. From a small number of cells floating in the fluid, a karyotype of the baby can be prepared, enabling the detection of many chromosome abnormalities, including common trisomic disorders.
3. Routine tests are now carried out to detect Down syndrome conditions in the fetuses in older mothers. Termination of such pregnancies is increasingly common in some western countries, reducing the incidence in this age group.

Genetic Counseling (page 204)

1. **Carrier screening** would allow the parents to ascertain the risk of conceiving a child with the family genetic disorder. This information could then be used to explore alternative methods of conceiving a child that is at lower risk of inheriting the disorder.
2. (a) Huntington disease persists because those with the mutation are able to reproduce and pass on the disorder before its effects are expressed.
(b) Presymptomatic genetic testing would allow carriers of the Huntington gene to make informed choices when considering starting a family.

Aneuploidy in Humans (page 205)

1. Embryos from left to right: XXY, XO, XXY, XO.
2. (a) Trisomic female (metafemale) (or superfemale)
(b) Klinefelter syndrome
(c) Turner syndrome
3. The YO configuration has no X chromosome (the X contains essential genes not found on the Y).
4. (a) For karyotype A: Circle X chromosome
Chromosome configuration: 45, X (44 + X)
Sex: female
Syndrome: Turner
(b) For karyotype B: Circle XXY chromosomes
Chromosome configuration: 47, XXY (44 + XXY),
Sex: male
Syndrome: Klinefelter
5. Number of Barr bodies:
(a) Jacob syndrome: 0
(b) Klinefelter syndrome: 1
(c) Turner syndrome: 0
6. X chromosome inactivation ensures that the proteins encoded by the genes on the X chromosomes will only be produced by the one active copy.
7. (a) **Nullisomy**: 0, both of a pair of homologous

chromosomes are missing.

- (b) **Monosomy**: 1, one chromosome appears instead of the normal two.
- (c) **Trisomy**: 3, three chromosomes appear instead of two, the result of faulty meiosis.
- (d) **Polysoy**: 3+, the condition in which one or more chromosomes are represented more than twice in the cell (includes trisomy).

Down Syndrome (page 207)

1. Autosomal aneuploidies are aneuploidies of the autosomal chromosomes, whereas sex chromosome aneuploidies affect the sex chromosomes (X and Y). (Aneuploidy refers to having a chromosome number that is not an exact multiple of the normal haploid set for the species).
2. (a) Having an extra chromosome may allow for the overproduction of some proteins. Having an extra copy of the gene on the third chromosome may result in more mRNA being produced for that gene.
(b) **Syndrome**: A suite of symptoms that typically occur together that result from a particular genetic condition. In Down, the syndrome is characterized by a collective suite of abnormalities affecting the face, limbs, internal organs, and musculature.
3. (a) Non-disjunction, which is the failure of chromosome 21 in one of the parents to separate during gamete formation (meiosis). Proportion: 92%.
(b) Down syndrome phenotype: Mental retardation, retarded growth and short stature, upward slanting eyes, stubby fingers, and folds in the inner corners of the eyes. They also tend to suffer from congenital heart disease.
4. Either one of:
– Translocation: One parent (a carrier) has chromosome 21 fused to another chromosome (usually number 14). Proportion: less than 5%.
– Mosaic: Failure of chromosomes 21 to separate in only some cell lines during mitosis (very early in embryonic development). Proportion: less than 3%.
5. 47

Alleles (page 210)

1. (a) Heterozygous: Each of the homologous chromosomes contains a **different** allele for the gene (one dominant and one recessive).
(b) Homozygous dominant: Each of the homologous chromosomes contains an identical dominant allele.
(c) Homozygous recessive: Each of the homologous chromosomes contains an identical recessive allele.
2. (a) **Aa** (b) **AA** (c) **aa**
3. Each chromosome of a homologous pair comes from a different parent: one of maternal origin, one of paternal origin (they originated from the egg and the sperm that formed the zygote). They contain the same sequence of genes for the same traits, but the versions of the genes (alleles) on each chromosome may differ.
4. **Alleles** are different versions of the same gene that code for the same trait. Different alleles provide phenotypic variation for the expression of a gene. There are often two alleles for a gene, one dominant

and one recessive. In this case, the dominant allele will be expressed in the phenotype. Sometimes alleles for a gene can be equally dominant, in which case, both alleles will be expressed in the phenotype. Where three or more alleles for a gene exist (multiple alleles), there is more phenotypic variation in the population (for that trait) than would be the case with just two alleles.

Mendel's Pea Plant Experiments (page 211)

1. and 2. (see table below):

	Dominant	Recessive	Ratio
Seed color	Yellow	Green	3.01 : 1
Pod color	Green	Yellow	2.82 : 1
Flower position	Axial	Terminal	3.14 : 1
Pod shape	Constricted	Inflated	2.95 : 1
Stem length	Tall	Dwarf	2.84 : 1

3. (a) Seed shape (2.96:1), seed color (3.01:1), and pod shape (2.95:1).

(b) Considering all the traits, larger sample sizes generally produced ratios closer to the predicted theoretical ratio. Smaller samples are more likely to produce results that deviate from the theoretical ideal, because they are affected more by the randomness of meiosis and fertilization.

Mendel's Laws of Inheritance (page 212)

1. Particulate inheritance: Inherited characteristics are transmitted by discrete entities (genes) which themselves remain unchanged from generation to generation. **Note:** Flower color is controlled by two alleles, a dominant purple one and a recessive white one. All offspring receive one of each of the alleles, but only the dominant one is expressed. In subsequent offspring, recessive alleles may be provided by each of the gametes to produce white flowers.

2. **Note:** During meiosis, the two alleles for a gene will separate into different gametes, and subsequently into different offspring. Normally both alleles cannot end up in the same offspring. Occasionally, faulty meiosis can occur, resulting in aneuploidy or polyploidy.

(a) Aa (b) A, A, a, a (c) 2 kinds: A and a

3. **Note:** During meiosis, all combinations of alleles are distributed to gametes with equal probability. The pair of alleles for each gene are sorted independently of those for all other genes. Genes that are linked on the same chromosome tend to be inherited together.

(a) AB and ab (b) 4 kinds: AB, Ab, aB, ab

Basic Genetic Crosses (page 213)

1.

	YYRR	YYRr	YyRR	YyRr
YYRR	YYRR	YYRr	YyRR	YyRr
YYRr	YYRr	YYrr	YyRr	Yyrr
YyRR	YyRR	YyRr	yyRR	yyRr
YyRr	YyRr	Yyrr	yyRr	yyrr

2. Yellow-round: 9/16 Yellow-wrinkled: 3/16
Green-round: 3/16 Green-wrinkled: 1/16

3. Ratio: 9 : 3 : 3 : 1

Monohybrid Cross (page 214)

	Genotype	Phenotype
Cross 2	50% BB 50% Bb	100% black
Cross 3	25% BB 50% Bb 25% bb	75% black 25% white
Cross 4	100% BB	100% black
Cross 5	50% Bb 50% bb	50% black 50% white
Cross 6	100% bb	100% white

Dominance of Alleles (page 215)

1. (a) Incomplete dominance: Neither allele is dominant (neither can mask the other).
(b) Codominance: Two or more alleles are dominant over any recessive alleles; both are fully expressed.

2. (a) Incomplete dominance: Heterozygote's phenotype is intermediate between homozygous parents.

(b) Codominance: Heterozygotes have a phenotype that is different from either homozygous parent.

3. Ratio: 1 : 2 : 1 (1 red : 2 roan : 1 white).

		Male gametes	
		C ^R	C ^W
Female gametes	C ^R	C ^R C ^R	C ^R C ^W
	C ^W	C ^R C ^W	C ^W C ^W

4. Parents: white and pink. Will produce 50% pink and 50% white offspring.

		Male gametes	
		C ^W	C ^W
Female gametes	C ^R	C ^R C ^W	C ^R C ^W
	C ^W	C ^W C ^W	C ^W C ^W

5. (a) Diagram labels:

	White bull	Roan cow
Parent genotype:	C ^W C ^W	C ^R C ^W
Gametes:	C ^W , C ^W	C ^R , C ^W
Calf genotypes:	C ^R C ^W , C ^W C ^W	C ^R C ^W , C ^W C ^W
Phenotypes:	Roan, white	Roan, white

(b) Phenotype ratio: 50% roan, 50% white (1:1)

(c) By choosing only the roan calves (male and female) to breed from. Initial offspring from roan parents should include all phenotypes: white, roan and red. By selecting just the red offspring from this generation it would be possible to breed a pure herd of red cattle. The unwanted phenotypes must be prevented from breeding (e.g. by castration).

6. (a) Diagram labels:

	Unknown bull	Roan cow
Parent Genotype:	C ^R C ^R	C ^R C ^W
Gametes:	C ^R , C ^R	C ^R , C ^W
Calf Genotypes:	C ^R C ^R , C ^R C ^W , C ^R C ^R , C ^R C ^W	
Phenotypes:	Red, Roan, Red, Roan	

(b) Unknown bull: **red** bull

7. (a) Diagram labels:

Parent Genotype:	Pink $C^R C^W$	Red $C^R C^R$
Gametes:	C^R, C^W	C^R, C^R
Offspring:	$C^R C^R, C^R C^W, C^R C^W, C^R C^W$	
Phenotypes:	Red, Red, Pink, Pink	

(b) Phenotype ratio: 50% red, 50% pink (1:1)

Multiple Alleles in Blood Groups (page 217)

Note: In this activity, any reference to the I alleles has been removed on the advice of researchers involved in the latest work in this area. References to the I gene are now considered to be incorrect and misleading.

1. Blood group table:

Blood group B	BB, BO
Blood group AB	AB

2. **Cross 2** **Group O** **Group O**
 Gametes: O, O O, O
 Children's genotypes: OO, OO OO, OO
 Blood groups: O, O O, O

Cross 3 **Group AB** **Group A**
 Gametes: A, B A, O
 Children's genotypes: AA, AO BA, BO
 Blood groups: A, A AB, B

Cross 4 **Group A** **Group B**
 Gametes: A, A B, O
 Children's genotypes: AB, AO AB, AO
 Blood groups: AB, A AB, A

Cross 5 **Group A** **Group O**
 Gametes: A, O O, O
 Children's genotypes: AO, AO OO, OO
 Blood groups: A, A O, O

Cross 6 **Group B** **Group O**
 Gametes: B, O O, O
 Children's genotypes: BO, BO OO, OO
 Blood groups: B, B O, O

Note: Depending on which gamete circle each symbol of a gene is placed, it is possible to have the answers arranged differently. There are of course many more crossover combinations possible.

3. (a) Parent genotypes:

Parent genotype:	AO	OO
Gametes:	A, O	O, O
Children's genotypes:	AO, AO	OO, OO
Blood groups:	A, A	O, O

(b) 50% (c) 50% (d) 0%

4. (a) Possible parent genotypes: Mother assumed to be heterozygous to get maximum variation in gametes (homozygous would also work).

Phenotypes	Group A	Group O
Genotypes:	AO	OO
Gametes:	A, O	O, O

Child's genotype would have to be AO or OO

(b) Therefore the only possible offspring from this couple would have been children with group **A** or group **O**. The man making the claim could not have been the father of the child.

5. (a) **A** or **B**

(b) **AB, A, B** or **O**

Dihybrid Cross (page 219)

Cross N° 1: Q1-3 integrated

Genotypes	BbLL	2	bbLL	4
and ratios:	BbLl	4	Bbll	2
	bbLL	2	bbll	2

Phenotypes	6 black/short	6 white/short
and ratios:	2 black/long	2 white/long

Cross N° 2: Q1-4 integrated

Gametes: White parent: all bL
 Black parent: Bl, Bl, bl, bl

Genotypes	BbLl	8	bbLl	8
and ratios:	1:1 ratio			

Phenotypes	8 black/short	8 white/short
and ratios:	1:1 ratio	

Sex Determination (page 221)

1. Presence of the Y chromosome (XX female, XY male).
2. The males have differing sex chromosomes (X and Y).

Lethal Alleles (page 222)

1. **Recessive** lethal alleles are lethal only when they occur in the homozygous recessive state, whereas **dominant** lethal alleles are either lethal even when only one copy of the allele is present, or they produce a measurable effect in the heterozygote.
2. (a) M^M- and MM (M^M-M^M is lethal, see below).
 (b) Phenotype ratio of 2:1 Manx: normal. The homozygous dominant condition (M^M-M^M) is **lethal** and embryos with this genotype are resorbed and never appear.
3. Some dominant lethal alleles, including Huntington's, do not take effect until after the onset of adulthood, i.e. after those with the genotype have reached reproductive maturity. There is a chance to pass the allele onto children before it takes effect.

Problems in Mendelian Genetics (page 223)

1. **Note:** Persian and Siamese parents are pedigrees (truebreeding) and homozygous for the genes involved.
 (a) Persian: UuSs, Siamese: uuSS, Himalayan: uuSS
 (b) F₁: Genotype: all heterozygotes UuSs.
 (c) F₁: Phenotype: all uniform color, short haired.
 (d) F₂ generation: UuSs X UuSs

	US	Us	uS	us
US	UUSS	UUSs	UuSS	UuSs
Us	UUSs	UUss	UuSs	Uuss
uS	UuSS	UuSs	uuSS	uuSs
us	UuSs	Uuss	uuSs	uuss

- (e) 1:15 or 1/16 uuss: Himalayan
- (f) Yes (only one type of allele combination is possible)
- (g) 3:13 or 3/16 (2 uuSs, 1 uuSS)
- (h) All of the following have different genotypes but produce a uniform color-short hair cat:
 UUSS, UuSS, UuSs, UUss, because they all have

at least one dominant allele for each gene. Similarly uuSs and uuSS both produce a color pointed short hair cat, and UUss and Uuss both produce a uniform colored, long hair cat.

- (i) Test cross with a Himalayan (i.e. double homozygous recessive: uuss). If any heterozygous cats are presented for mating then some of their offspring could be expected to be long-haired.
2. (a) **bbSS** (brown/spotted) X **BBss** (solid/black) (which parent was male and which female is unknown. Parents must be homozygous since all the offspring are of one type: BbSs: black spotted)
- (b) F_2 generation: BbSs X BbSs

	BS	Bs	bS	bs
BS	BBSS	BBSs	BbSS	BbSs
Bs	BBSs	BBss	BbSs	Bbss
bS	BbSS	BbSs	bbSS	bbSs
bs	BbSs	Bbss	bbSs	bbss

- (c) Spotted/black 9/16
Spotted/brown 3/16
Solid/black 3/16
Solid/brown 1/16
Ratio: 9:3:3:1 (described as above)
- (d) Dihybrid cross (no linkage)
3. (a) F_1 : Genotype: all heterozygotes RrBb.
(b) F_1 : Phenotype: all rough black coats.
(c) F_2 generation: RrBb X RrBb

	RB	Rb	rB	rb
RB	RRBB	RRBb	RrBB	RrBb
Rb	RRBb	RRbb	RrBb	Rrbb
rB	RrBB	RrBb	rrBB	rrBb
rb	RrBb	Rrbb	rrBb	rrbb

- (d) Rough/black 9/16
Rough/white 3/16
Smooth/black 3/16
Smooth/white 1/16
Ratio: 9:3:3:1 (described as above)
- (e) F_2 generation: RrBb X RrBb

	RB	RB	RB	RB
RB	RRBB	RRBB	RRBB	RRBB
Rb	RRBb	RRBb	RRBb	RRBb
rB	RrBB	RrBB	RrBB	RrBB
rb	RrBb	RrBb	RrBb	RrBb

- (f) F_2 Phenotype: all rough black coats.
(g) F_2 generation: RrBb X rrb

	rb	rb	rb	rb
RB	RRBb	RRBb	RRBb	RRBb
Rb	Rrbb	Rrbb	Rrbb	Rrbb
rB	rrBb	rrBb	rrBb	rrBb
rb	rrbb	rrbb	rrbb	rrbb

- (h) Note that this is also a back cross, since the cross is back to the parental phenotype.
Rough/black 4/16 (RrBb)
Rough/white 4/16 (Rrbb)

Smooth/black 4/16 (rrBb)
Smooth/white 4/16 (rrbb)
Ratio: 1:1:1:1 (described as above)

- (i) The parent's genotype: RrBb X Rrbb

4. The homozygous condition (CC^{L-}) is lethal. Normal birds are CC. The alleles show incomplete dominance, which is why the heterozygous condition (CC^L) produces creeper birds with a particular phenotype (short wings/legs). A cross between two creepers produces two creepers to every one normal bird (not three creepers as would be expected if the allele was not lethal in its homozygous condition).
5. Probability of black offspring: $(2/3 \times 1/4) = 1/6$ or 0.16

Working: The parents genotypes are Bb X Bb, and 1/3 of the white offspring (BB) crossed with Bb will result in no black lambs while 2/3 of the white offspring (Bb) crossed with Bb will result in 1/4 black lambs.

6. (a) Genotypes: $1/2 M^R M^R$, $1/2 M^R m$
Phenotypes: All restricted mallard pattern
- (b) Genotypes: $1/2 M^R M^R$, $1/2 M^R m$
Phenotypes: All restricted mallard pattern
- (c) Genotypes: $1/4 M^R M^R$, $1/4 M^R m$, $1/4 M^R m$, $1/4 M m$
Phenotypes: 3/4 restricted mallard pattern, 1/4 mallard pattern
Ratio: 3 restricted mallard : 1 mallard pattern
- (d) Genotypes: $1/4 M^R M^R$, $1/4 M^R m$, $1/4 M m$, $1/4 m m$
Phenotypes: 1/2 restricted mallard pattern, 1/4 Mallard pattern, 1/4 dusky mallard pattern
Ratio: 2 restricted mallard : 1 mallard : 1 dusky mallard pattern
- (e) Genotypes: $1/2 M m$, $1/2 m m$
Phenotypes: 1/2 mallard pattern, 1/2 dusky mallard pattern
Ratio: 1 mallard : 1 dusky mallard pattern
7. $1/2 Ww$ and $1/2 ww$
Ratio: 1 wire-haired : 1 smooth haired
Working: The parental genotypes are Ww X Ww. The test cross of the F_1 is to a smooth haired dog (ww). 1/4 of the F_1 will be wire-haired dogs (WW). When crossed with ww the result will be all wire-haired dogs (Ww). 1/2 of the F_1 will be wire-haired dogs (Ww). When crossed with ww, the result will be 1/2 wire-haired and 1/2 smooth-haired dogs. 1/4 of the F_1 will be smooth-haired dogs (ww). When crossed with ww, all offspring will smooth-haired (ww).

Dihybrid Cross with Linkage (page 225)

1. Crossover value (COV) for the offspring of the test cross: For crossover value, use the formula:
No. of recombinants ÷ total no. of offspring X 100
 $(21 + 27) \div (123 + 21 + 27) \times 100$
 $= (48 \div 300) \times 100 = 16\%$

Genomic Imprinting (page 226)

1. (a) **Genomic imprinting** (or parental imprinting) is part of epigenetics, the study of heritable changes in gene function that occur without involving changes in the DNA sequence. It occurs during gametogenesis in which the expression of a small subset of genes depends on whether the genes are inherited from the mother or father (the parent-of-

origin effect).

(b) Imprinting is achieved by (any one of):

- DNA methylation of the allele contributed by one parent, making an offspring effectively homozygous for the other parent's allele.
- Inheritance of two homologous copies of a gene from one parent (called uniparental disomy).

2. Imprinting is significant to the inheritance of some genes as imprinting will affect their phenotypic expression. For example, the same mutation, a specific deletion on chromosome 15, produces two different human genetic disorders depending on whether the mutation is inherited from the mother or the father.

Human Genotypes (page 227)

This will vary with each individual's collection of genes, e.g.

Thumb	Hh	Hyperextension
Ear lobes	FF	Free
Chin cleft	DD	Dimpled
Middle digit hair	Mm	Hair
Handedness	RR	Right
Hand clasp	cc	Right thumb on top

Sex Linkage (page 229)

1. Parent genotype: $X_O X_o$ $X_O Y$
 Gametes: X_O, X_o X_O, Y
 Kitten genotypes: $X_O X_O, X_O X_o$ $X_O X_o, X_o Y$

Genotypes **Phenotypes**

Male kittens: $X_O Y$ Black
 Female kittens: $X_O X_o$ Tortoiseshell

2. Parent genotype: $X_O X_o$ $X_O Y$
 Gametes: X_O, X_o X_O, Y
 Kitten genotypes: $X_O X_O, X_O X_o$ $X_O Y, X_o Y$
 Phenotypes: Orange female, Black male, Tortoise female, Orange male

(a) Father's genotype: $X_O Y$
 (b) Father's phenotype: Orange

3. Parent genotype: $X_O X_o$ $X_O Y$
 Gametes: X_O, X_o X_O, Y
 Kitten genotypes: $X_O X_O, X_O X_o$ $X_O X_o, X_o Y$
 Phenotypes: Tortoise female, Tortoise female, Black male, Black male

(a) Father's genotype: $X_O Y$
 (b) Father's phenotype: Orange
 (c) Yes, the same male cat could have fathered both litters.

4. Parent: Normal wife Affected husband
 Parent genotype: XX $X_R Y$
 Gametes: X, X X_R, Y
 Children's genotypes: $X_R X, XY$ $X_R X, XY$
 Phenotypes: Affected girl, Affected girl, Normal boy, Normal boy

(a) Probability of having affected children = 50% or 0.5
 (b) Probability of having an affected girl = 50% or 0.5
 However, all girls born will be affected = 100%
 (c) Probability of having an affected boy = 0% or none

5. Parent: Affected wife Normal husband
 Parent genotype: $X_R X$ XY
 Gametes: X_R, X X, Y
 Children's genotype: $X_R X, X_R Y$ XX, XY

Phenotypes: Affected girl, Normal girl,
 Affected boy, Normal boy

Note: Because the wife had a normal father, she must be heterozygous since her father was able to donate only an X-chromosome with the normal condition.

- (a) Probability of having affected children = 50% or 0.5
 (b) Probability of having an affected girl = 25% or 0.25
 However, half of all girls born may be affected.
 (c) Probability of having an affected boy = 25% or 0.25
 However, half of all boys born may be affected.

Background information for question 6: Sex linkage refers to the location of genes on one or other of the sex chromosomes (usually the X, but a few are carried on the Y). Such genes produce an inheritance pattern which is different from that shown by autosomes:

- Reciprocal crosses produce different results (unlike autosomal genes that produce the same results).
- Males carry only one allele of each gene.
- Dominance operates in females only.
- A 'cross-cross' inheritance pattern is produced: father to daughter to grandson, etc.

6. Sex linkage is involved in a number of genetic disorders (below). X-linked disorders are commonly seen only in males (the heterogametic sex), because they have only one locus for the gene and must express the trait. If the sex linked trait is due to a recessive allele, females will express the phenotype only when homozygous recessive. It is possible for females to inherit a double dose of the recessive allele (e.g. a color blind daughter can be born to a color blind father and mother who is a carrier), but this is much less likely than in males. X-linked genes include those that control:

- Blood clotting: A recessive allele for this gene causes hemophilia. It affects about 0.01% of males but is almost unheard of in females.
- Normal color vision: A recessive allele causes red-green color blindness affecting 8% of males but only 0.7% of females.
- Antidiuretic hormone production: A version of this gene causes some forms of diabetes insipidus.
- Muscle development: A rare recessive allele causes Duchene muscular dystrophy.

Inheritance Patterns (page 231)

1. Autosomal recessive:

(a) Punnett square:

Male parent phenotype:

Normal, carrier

Female parent phenotype:

Normal, carrier

(b) Phenotype ratio:
 Normal 3 Albino 1

	P	p
P	PP	Pp
p	Pp	pp

2. Autosomal dominant:

(a) Punnett square:

Male parent phenotype:

Woolly hair

Female parent phenotype:

Woolly hair

(b) Phenotype ratio:
 Normal 1 Woolly 3

	W	w
W	WW	Ww
w	Ww	ww

3. Sex linked recessive:

- (a) Punnett square:

Male parent phenotype:

Normal

Female parent phenotype:

Normal, carrier

- (b) Phenotype ratio:

Females:

Normal 2 Hemophiliac 0

Males:

Normal 1 Hemophiliac 1

	(X)	(X_h)
(X)	XX	XX _h
(Y)	XY	X _h Y

4. Sex linked dominant:

- (a) Punnett square:

Male parent phenotype:

Affected (with rickets)

Female parent phenotype:

Affected (with rickets)

- (b) Phenotype ratio:

Females:

Normal 0 Rickets 2

Males:

Normal 1 Rickets 1

	(X_R)	(X)
(X_R)	X _R X _R	X _R X
(Y)	X _R Y	XY

Pedigree Analysis (page 232)

- Pedigree chart of your family:** Each chart will be unique to each student. The chart should be drawn up carefully with a ruler, using the symbols illustrated at the top of the page called 'Pedigree Analysis' in your workbook. Students who do not know their biological family tree (e.g. they are adopted) can do it for their adoptive family or that of another student.
- (a) Dominant; each individual has an affected parent.
(b) Not sex-linked: Some of the daughters of the affected parent (I-3) are not affected. They would be if the gene were located on the X chromosome.
- (a) Explanatory background: I1 is a normal male, while the mother (I-2) must be a **carrier** (heterozygous) because she gave birth to both a normal and hemophiliac son. There is a 50% probability that II-2 is heterozygous (she could have received either of her mother's X chromosomes). If a carrier woman has children by a normal man then 25% of their children can be expected to be a hemophiliac. Because there is uncertainty as to whether the woman is a carrier or not, the total probability of II-2 producing hemophiliac children is:
Probability of being a carrier X probability of producing hemophiliac children if she is a carrier =? ie. $1/2 \times 1/4 = 1/8$ (12.5%).
(b) $1/4$ (25%). Because her first child was a hemophiliac, she must be a carrier.
(c) $3/4$ (75%). II-4 has a 50% chance of being a carrier. If she was a carrier and has children with a hemophiliac man, $1/2$ of their children (boys and girls) are expected to be hemophiliac. The combined chance of II-4 being a carrier and producing a hemophiliac child is $1/2 \times 1/2 = 1/4$. Therefore the probability that the child will be normal is the complementary fraction ($3/4$).
(d) It is impossible to determine the phenotype of the father of I1 from the information given, because the father could be either normal or a hemophiliac and still produce a daughter (I-1) that is a carrier (heterozygous normal).

4. (a) 1/2 (b) 0 (c) 0

- (d) 3/4

- (e) 1/2

Interactions Between Genes (page 234)

- Polygeny** refers to the determination of a single trait (e.g. skin color) by two or more genes. In contrast, **pleiotropy** is the situation where one gene affects several traits. One example is the sickle cell mutation, which has pleiotropic effects because a large number of traits are influenced by the possession of mutant hemoglobin. **Epistasis** describes the situation where one gene masks or otherwise alters the expression of other genes. A well known example is albinism; if an animal is homozygous recessive for color, it will be albino regardless of any other coat color genes it has.
- (a) Point mutation to the gene coding for the production of the β chain of the hemoglobin molecule.
(b) Hb^SHb^S
(c) Primarily, deformed red blood cells resulting in anemia and clumping of the red blood cells. The clumping causes circulatory problems and organ damage and, eventually, death.
(d) Although this mutation results primarily in a faulty hemoglobin molecule, this also affects the shape of the red blood cells and leads to the suite of other abnormalities associated with the disease.

Collaboration (page 235)

- No. of possible phenotypes: 4
- Pea comb: rrP₋ Single comb: rrpp
Rose comb: R₋pp Walnut comb: R₋P₋
- See the Punnett square below.

		Sperm			
		(RP)	(Rp)	(rP)	(rp)
Eggs	(RP)	RRPP Walnut	RRPp Walnut	RrPP Walnut	RrPp Walnut
	(Rp)	RRPp Walnut	RRpp Rose	RrPp Walnut	Rrpp Rose
	(rP)	RrPP Walnut	RrPp Walnut	rrPP Pea	rrPp Pea
	(rp)	RrPp Walnut	Rrpp Rose	rrPp Pea	rrpp Single

Ratio: Walnut : Pea : Rose : Single
9 : 3 : 3 : 1

- Parent genotypes:
(a) Rrpp (rose) X RrPp (walnut)
(b) rrpp (single) X RrPp (walnut)
(c) RRpp (rose) X rrPp (pea)

Complementary Genes (page 236)

- No. of possible phenotypes: 2
- Purple flower:** A and B must be present (i.e. a dominant allele for each gene).
White flower: Either A or B must be absent (i.e. at least one of the genes must have no dominants).

		Pollen			
		AB	Ab	aB	ab
Ova	AB	AABB Purple	AABb Purple	AaBB Purple	AaBb Purple
	Ab	AABb Purple	AAbb White	AaBb Purple	Aabb White
	aB	AaBB Purple	AaBb Purple	aaBB White	aaBb White
	ab	AaBb Purple	Aabb White	aaBb White	aabb White

flowers : White flowers
9 : 7

Ratio: Purple

- Parent genotypes: aaBb (white) X AaBb (purple)
White flowered parent must be missing both dominant alleles in at least one gene (e.g. AAbb, aaBB, Aabb, aaBb, aabb). Purple flowered parent must possess a dominant allele for each gene.
- Parent genotypes: AaBb (purple) X AaBb (purple)
Both parents had to possess a copy of the dominant allele for each gene in order to be purple. They also must have a recessive allele for each gene in order to produce some offspring that are white.
- Parent genotypes: aaBb (white) X Aabb (white).
Both parents must be homozygous recessive for different genes (they are both white), but possess a dominant allele for the other gene (since they produce some offspring that are purple).

Polygenes (page 237)

- Number of possible phenotypes: 5
- Black: AABB (all four dominant)
Medium: Any two dominant alleles (e.g. aaBB, AaBb)
White: aabb (all four recessive)
-

		Sperm			
		AB	Ab	aB	ab
Eggs	AB	AABB Black	AABb Dark	AaBB Dark	AaBb Medium
	Ab	AABb Dark	AAbb Medium	AaBb Medium	Aabb Light
	aB	AaBB Dark	AaBb Medium	aaBB Medium	aaBb Light
	ab	AaBb Medium	Aabb Light	aaBb Light	aabb White

Ratio: White : Light : Medium : Dark : Black
1 : 4 : 6 : 4 : 1

- All medium (AaBb)
- Black, dark, medium, light, white
- Seven phenotypes (number of dominant alleles present can range from none (aabbcc) to six (AABBCC)). A Punnett square would involve an 8 X 8 grid.
- Traits with **continuous variation** show a normal distribution curve when sampled and a graded variation in phenotype in the population. Such phenotypes are usually determined by a large number of genes and/or environmental influence. Examples include height, weight, hand span, foot size. In contrast, traits with **discontinuous variation** fall into one of a limited number of phenotypic variants and do not show a normal distribution curve when sampled. Differences in the phenotypes of individuals in a population are marked and do not grade into each other. Such phenotypes are usually controlled by a few different alleles at a few genes. Examples include ear lobe shape and tongue roll.
- Student's own plot. Shape of the distribution is dependent on the data collected. The plot should show a **statistically normal distribution** if sample is representative of the population and large enough.
 - Calculations based on the student's own data.
 - Continuous distribution, normal distribution, or bell shaped curve are all acceptable answers if the data conform to this pattern.
 - Polygenic inheritance: Several (two or more) genes are involved in determining the phenotypic trait. Environment may also have an influence, especially if traits such as weight are chosen.
 - A large enough sample size (30+) provides sufficient data to indicate the distribution. The larger the sample size, the more closely one would expect the data plot to approximate the normal curve (assuming the sample was drawn from a population with a normal distribution for that attribute).

Epistasis (page 239)

- No. of possible phenotypes: 3
- Black: B_C_ (a dominant allele for each gene)
Brown: A dominant allele for gene C only (e.g. Ccbb)
Albino: No dominant allele for gene C (e.g. ccBB, ccbb)
-

		Sperm			
		BC	Bc	bC	bc
Eggs	BC	BBCC Black	BBCc Black	BbCC Black	BbCc Black
	Bc	BBCc Black	BBcc Albino	BbCc Black	Bbcc Albino
	bC	BbCC Black	BbCc Black	bbCC Brown	bbCc Brown
	bc	BbCc Black	Bbcc Albino	bbCc Brown	bbcc Albino

Ratio: 9 Black: 3 Brown: 4 Albino

4. Homozygous white (bbcc) x homozygous black (BBCC):
Offspring genotype: 100% BbCc, phenotype: All black
5. Homozygous brown (bbCC) x homozygous black (BBCC):
Offspring genotype: 100% BbCC, phenotype: All black

What Genotype Has That Cat? (page 242)

Model answers cannot be provided for this exercise as there are so many different possible cat phenotypes. After the *Phenotype Record Sheet* has been completed, the extension exercise, where the genotype of each cat is identified should be completed on a separate sheet.

See the web sites linked from the Biozone web site www.thebiozone.com Under Bio Links: Genetics: Inheritance: • Coat color and pattern genetics of the domestic cat • Cat color genetics

What is Genetic Modification? (page 245)

1. Organisms may be genetically modified through:
 - The addition of a foreign gene, e.g. human insulin gene inserted into bacteria or yeast for the commercial production of human insulin.
 - Alteration of an existing gene so that a protein is expressed at a higher rate or in a different way. This GM technique is used in gene therapy.
 - Deletion or inactivation of an existing gene, e.g. the Flavr-Savr tomato which has had its ripening gene switched off. Gene inactivation also produces 'knock-out mice' which are used to study the physiological effects of particular genes.
2. (a) **Gene therapy:** A need/desire to find cures/treatments for genetic diseases (e.g. cystic fibrosis).
(b) **Transgenic organisms:** A need to accelerate traditional breeding programs by direct manipulation of the genome and a desire to improve the usefulness of livestock and crops by increasing production and reducing susceptibility to diseases and pests. There has also been a desire (need?) to produce new protein products by providing novel genes to make plants and animals into biofactories.
(c) **Plant micropropagation:** A desire for quick, large scale propagation of plant clones with superior traits, a need for disease free specimens, and a need to overcome seasonal growing restrictions.

Applications of GMOs (page 246)

1. Student's own research activity based on information provided in the student workbook or in other texts.

Restriction Enzymes (page 247)

1. (a) **Restriction enzyme:** Enzymes that cut DNA at very precise base sequences (they are able to create sticky end or blunt end junctions).
(b) **Recognition site:** The base sequence that a restriction enzyme recognizes and cuts.
(c) **Sticky end:** The exposed ends of DNA after a restriction enzyme has cut, leaving a partially unmatched base sequence.
(d) **Blunt end:** The exposed ends of DNA after a restriction enzyme has cut, leaving two blunt ends with no exposed nucleotide bases.
2. (a) *EcoRI*
(b) *Escherichia coli* RY13
(c) GAATTC
3. (a) GGATCC
(b) Recognition sites: See below.
(c) 5 fragments
4. There is a need to have a tool kit of enzymes that allows scientists to cut DNA at any point they wish. The action of such enzymes allows DNA to be manipulated for other recombinant DNA technologies.

Ligation (page 249)

1. (a) **Annealing:** The two single-stranded DNA molecules are recombined into a double-stranded form. Achieved by simple attraction of complementary bases (hydrogen bonds).
(b) **DNA ligase:** This enzyme joins together the two adjacent pieces of DNA by linking nucleotides in the sticky ends.
2. DNA ligase performs the task of linking together the Okazaki fragments during DNA replication.
3. It joins together DNA molecules, whereas restriction enzymes cut them up.

Gel Electrophoresis (page 250)

1. Purpose of **gel electrophoresis:** To separate mixtures of molecules (proteins, nucleic acids) on the basis of size and other physical properties.
2. (a) The frictional (retarding) force of each fragment's size (larger fragments travel more slowly than smaller ones).
(b) The strength of the electric field (movement is more rapid in a stronger field).
Note: The temperature and the ionic strength of the buffer can be varied to optimize separation.
3. The gel is full of pores (holes) through which the fragments must pass. Smaller fragments pass through these pores more easily (with less resistance and

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10      20      30      40      50      60
|AATGGGTACG|CACAGTGGATCC|ACG TAGTA|TGC GATGCGT|AGT G TTTATG|GAGAGAAGAA|
70      80      90      100     110     120
|AACGCGTCGC|CTTTTATCGA|TGCTGTACGGATGCGGAAGT|GGCGATGAGGATCCATGCAA|
130     140     150     160     170     180
|TCGCGGCCGA|TCGXGTAATA|TATCGTGGCT|GCGTTTATTA|TCGTGACTAG|TAGCAGTATG|
190     200     210     220     230     240
|CGATGTGACT|GATGCTATGC|TGACTATGCT|ATGTTTTTAT|GCTGATCCAGCGTAAGCAT|
250     260     270     280     290     300
|TTCGTCGCGTGGATCC|ATATCCCTTATATG|CATATATTC|TATACGGATCGCGCACGTTT|
  
```

therefore faster) than larger ones.

Polymerase Chain Reaction (page 251)

1. PCR produces large quantities of 'cloned' DNA from very small samples. Large quantities are needed for effective analysis. Minute quantities are often unusable.
2. A double stranded DNA is heated to 98°C for 5 min, causing the two strands to separate. Primer starting DNA polymerase are added to the sample. This is then incubated at 60°C for a few minutes during which time, complementary strands are created using each strand of the DNA sample as a template. The process is repeated about 25 times, each time the number of templates doubles over the previous cycle.
3. (a) Forensic samples taken at the scene of a crime (for example, hair, blood, or semen).
(b) Archeological samples from early human remains.
(c) Samples taken from the remains of prehistoric organisms preserved in ice, mummified, preserved in amber, tar pits etc.
4. This exercise can be done on a calculator by pressing the 1 button (for the original sample) and then multiplying by 2 repeatedly (to simulate each cycle). Most calculators will not display more than about 8 digits. Alternatively, use a computer spreadsheet.
(a) 1024 (b) 33 554 432 (33.5 x 106)
5. (a) It would be amplified along with the intended DNA sample, thereby contaminating the sample and rendering it unusable.
(b) Sources of contamination (any two of):
Dirty equipment (equipment that has DNA molecules left on it from previous treatments).
DNA from the technician (dandruff from the technician is a major source of contamination!)
Spores, viruses and bacteria in the air.
(c) Precautions to avoid contamination (any two of):
Using disposable equipment (pipette tips, gloves).
Wearing a **head cover** (disposable cap).
Use of **sterile procedures**.
Use of **plastic disposable tubes with caps** that seal the contents from air contamination.
6. (a) and (b) any of the following procedures require a certain minimum quantity of DNA in order to be useful: DNA sequencing, gene cloning, DNA profiling, transformation, making artificial genes. Descriptions of these procedures are provided in the workbook.

DNA Profiling Using PCR (page 253)

1. **STRs** (microsatellites) are non-coding nucleotide sequences (2-6 base pairs long) that repeat themselves many times over (repeats of up to 100X). The human genome has numerous different STRs; equivalent sequences in different people vary considerably in the numbers of the repeating unit. This property can be used to identify the natural variation found in every person's DNA since every person will have a different combination of STRs of different repeat length, i.e. their own specific genetic profile.
2. (a) **Gel electrophoresis**: Used to separate the DNA fragments (STRs) according to size to create the fingerprint or profile.

(b) **PCR**: Used to make many copies of the STRs. Only the STR sites are amplified by PCR, because the primers used to initiate the PCR are very specific.

3. (a) Extract the DNA from sample. Treat the tissue with chemicals and enzymes to extract the DNA, which is then separated and purified.
(b) Amplify the microsatellite using PCR. Primers are used to make large quantities of the STR.
(c) Run the fragments through a gel to separate them. The resulting pattern represents the STR sizes for that individual (different from that of other people).
4. To ensure that the number of STR sites, when compared, will produce a profile that is effectively unique (different from just about every other individual). It provides a high degree of statistical confidence when a match occurs.

DNA Chips (page 255)

1. Purpose: To determine the presence or sequence of genes in a sample, and the expression or activity level of those genes.
2. (a) The gene probes making up the microarray fluoresce when cDNA binds to them (called nucleic acid hybridization). This indicates that the RNA product has been expressed in the cell it was taken from. A quantitative amount of gene activity can be computer generated.
(b) Reverse transcriptase makes a single-stranded copy (cDNA) of the RNA extracted from a cell.
3. (a) Genes that turned red in the microarray (2 and 24) were over-expressed and therefore the most antibiotic resistant genes from the bacteria.
(b) New antibiotics would be designed to silence these genes that are antibiotic resistant. Alternatively, new antibiotics could also be developed to affect those bacterial genes that are not antibiotic resistant (e.g. genes 4, 17, and 22).
4. They have evolved from Southern Blotting techniques where fragmented DNA is attached to a substrate and then probed with a known gene or fragment. Many different DNA probes are incorporated into a DNA chip. Each spot on the chip has thousands-to-millions of copies of a probe and the color of the spot allows a quantitative read-out of a particular gene's activity in a cell. Advantages include identifying which genes are expressed in a particular tissue and to what extent.
5. The information gained from the microarray could be used to identify which tissue was cancerous and to what degree the cancer was present. This would then enable specialists to advise the best treatment for a particular cancer.

Automated DNA Sequencing (page 257)

1. (a) **Forensic science**: Samples of blood, semen, and hair left at the scene of a crime can be used to identify the perpetrator of a crime.
(b) **Legal disputes**: Arguments over paternity of humans (and lately, the pedigree of racehorses).
(c) **Medical applications**: Identification of genetic disorders in humans to provide opportunity for genetic counseling.

- (d) **Evolution/taxonomy:** Determining the genetic relatedness of groups of plants and animals to reassess the traditional classification models for those organisms (to produce a phylogenetic tree which reflects their evolutionary relationships).
- (e) **Archeology/anthropology:** Studies of the genetic makeup of modern human races to determine the geographic origin of modern humans and the timing of this event.
- (f) **Conserving endangered species:** Studies of populations of threatened species to determine the degree of genetic biodiversity. This is important for endangered species that have small populations with low genetic diversity due to in-breeding. The degree to which populations are genetically isolated from each other can also be determined.
- (g) **Livestock breeding programs:** Assist with the tracking of offspring from matings between livestock parents. Will also assist in the identification of transgenic offspring from mated transgenic parents.
2. The Human Genome Project required an **automated process** that could cope with the sequencing of the 3 billion bases making up the human genome. It has to be automated, rapid, and cost-effective (cheap to run).

Gene Cloning Using Plasmids (page 259)

1. **Restriction enzymes** are used to produce the DNA fragment (often a human gene) that is to be cloned, by isolating it from other DNA and providing it with sticky ends. The same enzymes are used to open up the plasmid or viral DNA into which the DNA fragment is to be inserted.
2. (a) A **molecular clone** is a self replicating recombinant DNA molecule, which is used to transmit a gene from one organism to another.
- (b) It is important that the molecular clone is self-replicating because it must act as a vector for the transmission of DNA between organisms. To do this effectively, it must be able to replicate inside its host without integration into the host's chromosome.
3. Once a gene has been isolated and inserted into a host organism for replication, the host organism can be made into a biological factory to manufacture unlimited quantities of a protein product (e.g. human insulin). Gene cloning can also be used to yield large quantities of a gene for medical applications (e.g. vectors for gene therapy) or to make transgenics for genetic research.
4. Recombinant colonies can be identified by their ability to grow on agar with ampicillin but not tetracycline.
- Grow the bacteria on agar containing ampicillin. All resulting colonies must contain the plasmid.
 - Press a sterile filter paper firmly onto the surface of the agar, taking care to mark the paper's position relative to the agar plate. Press the paper onto another agar plate containing tetracycline and mark the position of the paper relative to the plate. Any colonies that do not grow on this new agar must contain the recombinant DNA (as they have been killed by tetracycline).
 - Match the position of colonies between the first and second agar plates. Those on the first plate that are missing from the second are isolated and cultured.

Genetically Modified Plants (page 261)

1. (a) Grain size or number: Larger and more numerous.
 - (b) Maturation rate: Earlier or faster.
 - (c) Pest resistance: Broad range and increased tolerance to pests.
2. Some genes are nearly identical in different organisms. Because the functions of many genes have already been identified in the sequenced genomes of some key organisms, the same or similar genes (mapped by conventional means) are presumed to have the same or similar function in crop species. This saves time in identifying gene functions in species of interest.
3. *A. tumefaciens* has a large, tumor inducing plasmid which can infect plant cells and become incorporated into the plant's own genome. **Note:** The plasmid can be successfully modified and transferred to plant cells, where the genetic modification is taken up and expressed by the plant.
4. Increased protein content would be desirable in crops for developing countries where the staple diet is a cereal crop and the diet is generally protein deficient.

Transgenic Organisms (page 263)

1. (a) **Transgenesis:** The transfer of genes from one organism (usually another species) to another organism (so that the recipient takes on the characteristics encoded by the foreign DNA).
 - (b) **Foreign DNA:** DNA that is not part of the natural genome of a species.
2. The DNA of one organism is introduced (by way of a vector, direct injection, or protoplast fusion) into the genome of another (recipient) organism. The foreign DNA, when expressed, confers new properties on the recipient organism.
3. Examples include (any one):
- A gene that provides resistance to bacterial disease in rice plants.
 - A gene that provides resistance to a crop against herbicide sprays (so that weed control with herbicides will not affect the crop).
4. (a) to (c) any of the following: A need to:
- Treat genetic diseases in humans.
 - Improve production in livestock (milk, cheese, beef, mutton, wool, leather).
 - Increase pest resistance in crops and livestock.
 - Provide existing crops and livestock with (potentially useful) novel traits (e.g. timber with reduced lignin, cows milk with altered constituents).
 - Provide crops with an ability to synthesize their own fertilizer (to reduce dependence on application of agricultural fertilizers).
5. (a) **Advantages** (any two of): • Viruses are good vectors because they are adapted to gain entry into a host's cells • Viruses are very host specific with respect to infection • Viruses can integrate their DNA into that of the host.
- (b) **Disadvantage** (any of): • The host can develop a strong immune response to the viral vector (infection). In patients immune suppressed by their disorder, this severely undermines their health. • Retroviruses infect only dividing cells (uptake may

be sporadic or poor). • The inserted genes may only function sporadically because they are not inserted into the chromosome.

6. The purpose of this experiment was simply to show that the technology was viable and that a transgenic animal could be produced.

Gene Therapy (page 265)

1. (a) The purpose of gene therapy is to correct a genetic disorder of metabolism arising from the expression of a defective gene. **Note:** Some techniques involve culturing corrected cells ex-vivo. Injection of corrected cells into the patient relieves the symptoms of the disorder but does not cure it.
- (b) Three categories of disease targeted by gene therapy: Inherited genetic disorders of metabolism, cancers and other non-infectious acquired diseases, and infectious diseases (e.g. viral infections).
2. (a) **Transfection:** The transfer of genes from an infectious agent (such as a virus) to a recipient.
- (b) Transfection of germline cells allows the genetic changes to be inherited. In this way, a heritable disorder could be corrected in future generations.
3. **Gene cloning** is used to make multiple copies of the normal (corrective) allele.
4. **Enzyme disorders** are good candidates for gene therapy because enzymes are proteins and many are encoded by a single gene. Introducing a normal allele results in expression of that allele and production of the missing or defective protein (or polypeptide that forms part of the functional protein). This production will ease the symptoms of the missing or defective enzyme.

Vectors for Gene Therapy (page 266)

1. (a) Viruses are good vectors because they are adapted to gain entry into a host's cells and integrate their DNA into that of the host.
- (b) Viral vectors can cause problems because (two of):
 - The host can develop a strong immune response to the viral infection. In patients disadvantaged (immune suppressed) by their disorder, this could severely undermine their health.
 - Retroviruses infect only dividing cells.
 - Viruses may not survive if attacked by the host's immune system.
 - If they do not integrate into the chromosome, the inserted genes may only function sporadically.
 - The genes may integrate randomly into chromosomes and disrupt the functioning of normal genes (this occurred recently in retroviral vectors used in SCID gene therapy patients).
2. (a) If a therapeutic gene is integrated into the chromosome, it has a better chance of being stable in the cell and functioning properly in the long term.
- (b) When it integrates into the patient's chromosome, the gene has the potential to disrupt normally functioning genes (see 1(b) above). In recent gene therapy trials in SCID patients, retroviral vectors integrated preferentially into currently active genes.
3. (a) Naked DNA is unstable because it is recognized

as foreign and is easily degraded by the normal clean-up mechanisms occurring in the host's tissues (phagocytes etc.). Uptake by cells is inefficient and, once within the cell, the DNA is still at risk of degradation by lysosomes.

- (b) Liposomes offer greater stability because they are formulated so that they are recognized by the host's cell receptors and they target these receptors (so are more directed). They are therefore less likely to be degraded in the tissues.

Gene Delivery Systems (page 267)

1. (a) **CF symptoms:** Disruption of gland function including the pancreas, intestinal glands, biliary tree, sweat glands, and bronchial glands. Infertility occurs in males and females. Disruption of lung function produces the most obvious symptom; the accumulation of thick, sticky mucus in the lungs and associated breathing difficulties.
- (b) CF has been targeted because the majority of cases are the result of a gene defect involving the loss of only one triplet (three nucleotides). In theory, correction of this one gene should not be difficult.
- (c) Correction rate has been low (25%), and the effects of correction have been short lived and the benefits quickly reversed. These problems are related to the poor survival of the viral vector in the body and the sporadic functioning of the gene because it is not integrated into the host's (human) chromosome. Patients suffer problems with immune reaction to the vector. In one patient, treatment was fatal.
2. (a) **Vector:** Adenoviruses
Delivery: Piped directly into the lungs.
Potential problems: Gene may function only sporadically when not integrated into the host's chromosome. Adenoviruses have poor survival in the body and are quickly destroyed by the immune system. As a result, corrective rates are low and the effects of the corrective gene are short lived. Patients may show various adverse reactions as a result of their immune response to the viral vector.
- (b) **Vector:** Liposomes
Delivery: Delivered via inhalation of a spray formulation (in aerosol or nebulizer).
Potential problems: Liposomes are less efficient than viruses at transferring genes, so corrective rates are lower than for viral vectors.
3. (a) When an essential gene function is affected by gene therapy in somatic cells, the individual will be affected and there is a chance of corrective therapy in that person's lifetime. When the change affects germline cells, all descendants of the treated individual have a chance to inherit the disrupted gene, so a second heritable change is created.
- (b) Alteration of somatic cells to selectively alter one's phenotype is (presumably) a matter of one's own choice; it may benefit that person in their lifetime, but will not affect subsequent generations. When these selective changes affect the germline cells, then they are heritable and the alteration is not necessarily limited to one individual. This poses the problem of genetic selection and eugenics, and all their consequent ethical dilemmas.

Production of Human Proteins (page 269)

- (a) High cost (extraction from tissue is expensive).
(b) Non-human insulin (from pigs or cattle) is different enough from human insulin to cause side effects.
(c) The extraction methods did not produce pure insulin so the insulin was often contaminated.
- The insulin is synthesized as two (A and B) nucleotide sequences (corresponding to the two polypeptide chains) because a single sequence is too large to be inserted into the bacterial plasmid. Two shorter sequences are small enough to be inserted (separately) into bacterial plasmids.
- The β -galactosidase gene in *E. coli* controls the transcription of genes, so the synthetic "genes" must be tied to that gene in order to be transcribed.
- (a) Insertion of the gene: The yeast plasmid is larger and could accommodate the entire synthetic nucleotide sequence for the A and B chains as one uninterrupted sequence.
(b) Secretion and purification: Yeast, being eukaryotic, has secretory pathways that are more similar to humans than those of a prokaryote. Secretion from the cell of the precursor insulin molecules is thus less problematic. Purification would be simplified because removal of β -galactosidase is not required.
- Mass production of human proteins using GMOs facilitates a low cost, reliable supply for consumer use. The protein (e.g. insulin) is free of contaminants and, because it is a human protein, the side effects of its use are minimized.
- In the future, gene therapy, where a faulty gene is corrected in the patient, could treat many inherited disorders of metabolism. The use of stem cells, which can differentiate and proliferate in the patient's tissue, may prove the best way to correct genetic disorders.

The Human Genome Project (page 271)

- HGP:** Aims to map the entire base sequence of every chromosome in the human cell (our genome), to identify all genes in the sequence, determine what they express (protein produced), and determine the precise role of every gene on the chromosomes.
- A HapMap will allow researchers to find genes and genetic variations that affect health and disease. It will also be a powerful tool for studying the genetic factors contributing to variation in response to environmental factors, susceptibility to infection, effectiveness of drugs, and adverse responses to drugs and vaccines.
- (a) Medical (any of the following):
 - Will identify the location and sequence for up to 4000 known genetic diseases, opening up opportunities for drug therapy.
 - Will provide the information to enable the production of human proteins to correct metabolic deficiencies.
 - Will open up the possibility of gene therapy for many genetic diseases.
 - Will enable the development of new therapeutic drugs to block metabolic pathways.
 - With greater knowledge, emphasis will shift from treatment of disease to better diagnosis and prevention of disease.

- Screening for genetic predisposition to disease.
- The ability to sequence quickly and directly will revolutionize mutation research (direct study of the link between mutagens and their effects).
- (b) Non-medical (any of the following):
 - What we learn about human genetics will enable improvement of livestock management.
 - Provides a knowledge base that is a key to understanding the structure, function, and organization of DNA in chromosomes.
 - Provides the basis for comparative studies with other organisms (e.g. for taxonomic purposes).
 - Provides a greater understanding of human evolution and anthropology.
 - Facilitates developments in forensics.
- Proteomics** is the study (including identification) of the protein products of identified genes. It relies on the knowledge gained by the HGP, but will ultimately provide the most useful information because it will determine the biological function of the mapped genes.
- Student's own discussion. Suggestions for each issue listed in the table (pros and cons) are as follows:
 - Rights of third parties:
 - (a) They should have the genetic information in order to make an informed decisions (about insurance premiums etc.) to the benefit of those with favorable genetic test results.
 - (b) They should be denied the information because they could use it to unfairly discriminate against people with "unfavorable" genetic test results.
 - No treatment, therefore the knowledge is pointless:
 - (a) Although there may be no treatment initially, treatment may become available and knowledge of genetic predisposition will allow informed decisions to be made at short notice if necessary.
 - (b) Knowing that one has a disease and cannot do anything about it could create emotional problems for many people.

- High costs of tests:
 - Although the costs are high, the knowledge is important to a person's health and to medical research generally and is justifiable.
 - If costs are not met by public funds, the high costs will preclude those individuals who cannot personally afford them.
- Genetic information is hereditary:
 - Knowledge of an inherited disease or disorder lets family members assess their risk when planning their own lives (e.g. planning a family).
 - Family members may feel forced to not have children if their risk of an inherited disorder is high.

Genome Projects (page 273)

- Yeast: 461.5 (c) Fruit fly: 93.3
E. coli: 957.2 (d) Mouse: 12
- The amount of (protein)coding DNA ('genes') per Mb of DNA varies tremendously because different species have varying amounts of DNA in non-protein coding regions (regions traditionally not regarded as genes).
- Sequencing the genomes of major crop plants, such as wheat, rice, and maize, will improve the feasibility of making appropriate, high value, and safe genetic modifications to the plants. **Note:** These modifications

may be for characteristics such as improved pest resistance, higher yield, lower water demand, nitrogen fixation etc. Other reasons include a better understanding of crop diseases, growth potential, and genetic resilience in the face of selective (in)breeding.

4. (a) First animal genome sequenced: the nematode worm *Caenorhabditis elegans*
Date: December 1998 (source Wellcome Trust)
- (b) First plant genome sequenced: Thale cress, *Arabidopsis thaliana*, a weed related to mustard
Date: December 2000 (source, Nature)

Cloning by Embryo Splitting (page 274)

1. **Embryo splitting** is a much simpler technique than nuclear transfer and involves only the splitting of a normally produced embryo at a very early stage in development. The embryos continue to develop normally (as in the case of natural identical twins). There is no inducement of a somatic cell.
2. (a) Stem cells are undifferentiated; this allows them to be used to make any type of tissue in the recipient (a similar outcome for the production of blood cells is already achieved with bone marrow transplants).
- (b) Cloning high milk yielding cows will enable high yielding herds to be produced quickly (without waiting to see the phenotypic outcome of usual selective breeding processes). Ultimately, this will improve supply at low cost and may also free up land for other uses (since, theoretically, smaller herds would be required).
3. Continued use of embryo splitting will reduce the total pool of genetic diversity from which to select new breeds/strains/varieties.

Cloning by Nuclear Transfer (page 275)

1. **Cloning (using nuclear transfer)** involves producing genetically identical individuals from the non-embryonic (somatic) tissue of a known phenotype.
2. (a) **Switching off genes in the donor cell:** Induced by low nutrient medium (starvation of the egg).
- (b) **Fusion of donor and enucleated egg:** Induced by a short electric pulse.
- (c) **Activation of the cloned cell (reconstructed egg cell):** Induced by a second gentle electric pulse or by chemical means. A time delay of about 6 hours improves the success of the egg activation process, probably through the prolonged contact of the chromatin with (unknown) cytoplasmic factors.
3. (a) and (b) (any two of):
 - Production of clones from a proven phenotype that can quickly be disseminated into commercial herds.
 - Rapid production of transgenic animals that produce a particular product (e.g. a pharmaceutical secreted in the milk), in order to respond to market demand.
 - Conservation of rare livestock breeds. It is hoped that cloning will eventually be integrated into zoo management programs. By retaining the tissues of individuals before they die, some of the genetic diversity of rare species can be retained. It may even be possible, in the future, to restore species that are on the verge of extinction using cloning.

Organ Transplants (page 277)

1. Higher success rate of organ transplants due to:
 - (a) More effective and safer drugs to suppress immune rejection of the foreign organ.
 - (b) Improved techniques to match tissue type between donor and recipient.
 - (c) Better techniques for organ preservation and storage (during transfer from donor).
2. (a) Organ and tissue rejection occurs because the immune system recognizes the transplanted material as foreign and sets out to destroy it.
- (b) **Immunosuppressant drugs** suppress the immune system response to foreign tissue. **Tissue typing** is important because the better the match of the histocompatibility antigens between the donor and recipient the less chance there is of immediate rejection of the transplanted material.
- (c) Drugs that suppress the immune system response can make the patient vulnerable to everyday infections. Sometimes, these may prove fatal.
3. (a) **Xenotransplantation** (transplant of organs from non-human species). Promising techniques involve the use of mammals that have been genetically modified to produce organs compatible with human recipients.
- (b) **Tissue engineering**, using stem cells to create semisynthetic living organs to use as replacement parts. **Note:** this technique requires the isolation, selection, and cultivation of the cells, followed by assembly, transport, and transplant of the implant.
4. Some points of discussion below. This answer may also take the form of a debate or a separate report. Students are unlikely to cover all issues:
Human to human organ and tissue transplants:
FOR:
 - Organ donation is a unique opportunity to save lives, so there is an altruistic component to donation.
 - Advances in medical technology have improved preservation techniques so that the longevity of vital organs has been improved during recovery, transport, and transplant.
 - Improvements in stem cell technology in the future will reduce the risk of rejection.
 - National and international computerized networks matching donors and recipients reduce the time it takes to locate a suitable donor.
 - Improvements in transplant technique and immunosuppressant drugs have (in some cases) more than doubled the success rate of transplants in recent years.
 - Donating tissues or organs of family members has been shown to help a bereaved family to recover from loss.
 - All major religions approve of tissue and organ transplantation.
 - In most countries, it is still a crime to gain financially from organ donation.
 - Organ transplants are now standard medical procedure; one year survival rates are good (96% (kidney), >86% (heart), 88% (liver)).
 - People of all ages can donate organs.
 AGAINST
 - Organ donation can only take place under certain circumstances (e.g. accident and brain death, or death while in intensive care). Donor must be medically and legally dead.

- Despite advances, transplant recipients face several (avoidable) risks, including inappropriate selection and testing of donors and inadequate sterilization of some tissues. These increase the risk of infection, e.g. from prions, malignancies, and viruses such as West Nile. There is also the risk that the material for transplantation may be of poor quality (e.g. contaminated during storage or transport) and the chance of rejection therefore higher.
- Removal of a fraction of a kidney or liver from a living donor is not risk free for the donor, especially in countries with inadequate health care facilities. There is evidence that donors themselves end up on transplant waiting lists.
- Even well matched human transplants often fail.
- The growing reliance on living donors creates challenges for the guiding principles of the donor programs. Living donors must act voluntarily and without financial incentive (some policy makers want to allow payment for donation). Payment for organs increases the risk that donors will be medically unsuitable or put themselves at high risk.
- Global safety standards are not yet in place, despite regional guidelines. Issues of donor and recipient confidentiality are still to be fully addressed.
- Recipients need to continue with immunosuppressant drugs to prevent transplant rejection; these have their own side effects and complications.
- There is an widening gap between the need for organs and the number available.

Animal to human organ transplants (xenotransplants). Issues can be categorized into those associated with animal welfare and those associated with risks to humans (individuals or the wider community).

FOR:

- Transplants from animals would relieve some of the pressure on the human organ waiting list.

AGAINST:

- Xenotransplants are not very compatible with human tissues; rejection rates are still unacceptably high, even from GE animals (usually pigs).
- Xenotransplants involve genetic engineering of animals to produce human proteins that are more acceptable to the recipient. GE carries its own suite of ethical issues. "Humanizing" any animal is still unacceptable to many people.
- Xenotransplantation carries a risk for the wider community, the major concern being the cross-species transmission of infectious agents such as viruses (particularly retroviruses).
- Research to improve the success rate of xenotransplants is needed (especially testing animal to human transplants in clinical trials). These are difficult and expensive. Many argue that it would be better to pursue stem cell technologies and improve existing human to human transplant success rates.

The Ethics of GMO Technology (page 279)

1. Plants produce pollen which has the potential to be spread in a broadcast fashion (broadcast pollination). This increases the risk that genes (e.g. for herbicide resistance) will be transferred from a GM plant to a weed or other plant. **Note:** Such gene transference has already been demonstrated between plant species.

Transfer of sex cells (and therefore genes) between animals in this way does not occur; breeding in animals is generally a more precise and difficult process.

2. (a) **Advantage:** Crop growers could spray a field with herbicide to kill weeds without harming the crop.
(b) **Problem:** Herbicide resistance may be spread to weed plants by viral or bacterial vectors that infect plants. Encourages overuse of herbicide chemicals.
3. (a) **Advantage:** Ability to grow tropical food crops in regions that could not previously do so.
(b) **Problem:** Such plants in a new environment may become pest species. Underdeveloped economies that rely on tropical cash crops may suffer as a result of competition from economically strong countries.
4. (a) **Advantage:** Will allow regions that are poor in agricultural production to produce crops.
(b) **Problem:** Such plants in a new environment may become pest species. Disturbs natural wetland habitats, probably resulting in the loss of wetland and marsh native species.
5. (a) Enhancing wool production in sheep (yield and/or wool quality).
(b) Use of livestock animals as biofactories by producing useful proteins in their milk (especially cattle, but also sheep and goats).
6. The widespread use of antibiotic markers in food crops for human consumption or stock food may give rise to antibiotic resistant strains of pathogenic bacteria which affect humans and stock animals. Restrained use of antibiotics is now considered essential in preventing large scale development of antibiotic resistance.
7. (a) Introduces nitrogen fixing ability in non-legumes thereby reducing the need for nitrogen fertilizers.
(b) The bacterium would prevent attack on the seeds by pathogenic bacteria and fungi.
8. (a) Some points for discussion are:
 - That the GM product and/or the GMO could have some unwanted harmful effect on humans or other organisms.
 - That the genetic modification would spread uncontrollably into other organisms (breeding populations of the same or different species).
 - Consumer choice is denied unless adequate labeling protocols are in place. If everything contains GM products then there is no choice.
 - General fear of what is not understood (fear of real or imagined consequences).
 - Objections on the grounds that it is ethically and morally wrong to tamper with the genetic make-up of an organism.
 - Generation of monopolies where large companies control the rights to seed supplies and breeding stock.
- (b) Those that pose a real biological threat are:
 - Amongst plant GMOs, the indiscriminate spread of foreign genes.
 - Unusual physiological reactions e.g. allergies, to novel proteins.
 - Some animal rights issues may be justified if genetic modification causes impaired health.

Note: This question is not intended to imply that ethical or moral concerns are less valid than biological ones. It is merely an exercise in

identifying the nature of the biological concerns.

Components of an Ecosystem (page 282)

1. A **community** is a naturally occurring group of organisms living together as an ecological entity. The community is the biological part of the ecosystem. The **ecosystem** includes all of the organisms (the community) and their physical surroundings (the environment).
2. The **biotic factors** are the influences that are the result of the activities of living organisms in the community whereas the **abiotic** (physical) **factors** are the influences of the non-living part of the community e.g. climate.
3. (a) Population (c) Community
(b) Ecosystem (d) Physical factor

Biomes (page 283)

1. Northern extent of boreal forest limited by low temperatures and short daylight hours for half of the year (= short growing season), and the presence of a permanently frozen ground layer which prevents deep root hold in the soil (required by larger trees).
2. Less biomass is tied up in woody tissues (there are few trees) and turnover times for grasses are high (i.e. the plant tissue is replaced entirely with a high frequency).
3. These are rainshadow areas: dry areas in the leeward side of mountains in the path of rain-bearing winds. Much of the precipitation is dropped at high altitude in the mountain ranges as snow and ice, leaving a paucity of precipitation in lowland areas adjacent to mountains.
4. Most of the natural extent of temperate forest is mid-latitude with a reasonably equable climate and moderately high, evenly distributed rainfall. These factors make the forest area ideal for settlement and agriculture. Consequently, much of the original forest has now been cleared.

Physical Factors and Gradients (page 285)

1. Whereas **climate** refers to longer term, usually broad scale weather patterns in a region, the **microclimate** refers to climatic variation in a very small area or in a particular habitat. This can vary depending on shelter and aspect, as well as the influence of objects in the environment. It often refers to the immediate climate in which an organism lives.
2. High humidity underground, in cracks, under rocks.
3. In a crack or crevice, in a burrow underground, in spaces under rocks.
4. An animal unable to find suitable shelter would undergo heat stress, dehydration and eventually die.
5. High humidity enables land animals to reduce their water loss due to evaporation. This in turn reduces their demand for (and dependence on) drinkable water.
6. At night, temperature drops and humidity increases (to the point where condensation may occur; this is a source of valuable water for some invertebrates).

7. Environmental gradients from canopy to leaf litter:
 - (a) Light intensity: decreases.
 - (b) Wind speed: decreases.
 - (c) Humidity: increases.
8. Reasons why factors change:
 - (a) Light intensity: Foliage above will shade plants below, with a cumulative effect. The forest floor receives light that has been reflected off leaf surfaces several times, or passed through leaves.
 - (b) Wind speed: Canopy trees act as a wind-break, reducing wind velocity. Subcanopy trees will reduce the velocity even further, until near the ground the wind may be almost non-existent. An opening in the forest canopy (a clearing) can expose the interior of the forest to higher wind velocities.
 - (c) Humidity: The sources of humidity (water vapor) are the soil moisture, leaf litter, and the transpiration from plants. Near the canopy, the wind will carry away moisture-laden air. Near the forest floor, there is little wind, and humidity levels are high.
9. The color of the light will change nearer the forest floor. White light (all wavelengths) falling on the canopy will be absorbed by the leaves. Reflected light in the green wavelength bounces off the leaves and passes downward to lower foliage and the forest floor.
10. (a) **Advantages** (one of): Reduced wind speed reduces water loss due to transpiration; water balance (drying out) is not a problem. Increased humidity is an advantage for plants that are sensitive to water loss.
(b) **Disadvantages** (one of): There is a marked reduction in the quantity and quality of light available for photosynthesis. Plants on the forest floor are typically slow-growing and may have special leaf modifications to enhance light capture (e.g. large size and arrangement to avoid shadow effect).
11. Environmental gradients:
 - (a) Salinity: increases from LWM to HWM.
 - (b) Temperature: increases from LWM to HWM.
 - (c) Dissolved oxygen: decreases from LWM to HWM.
 - (d) Exposure: increases from LWM to HWM.
12. (a) Rock pools may have very low salinity if there has been rain falling into them directly or through runoff.
(b) Rock pools may have very high salinity due to evaporation after exposure without rainfall.
13. (a) **Mechanical force of wave action:** Point B will receive the full force of waves moving inshore, point A will receive only milder backwash, point C will experience surge but no direct wave impacts.
Surface temperature: Points A and B will experience greater variations in rock temperature depending upon whether the tide is in or out, day or night, water temperature, wind chill factors. Point C is more protected from some of these factors and will not experience the heating effect of direct sun.
(b) Microclimates.
14. Environmental gradients from water surface to bottom:
 - (a) Water temperature: Decreases gradually until below the zone of mixing when there is a sharp drop.
 - (b) Dissolved O₂: Oxygen at a uniform concentration until below the zone of mixing when there is a sharp drop, with little oxygen (or anoxia) at the bottom.
 - (c) Light penetration: Decreases at an exponential rate

(most light is absorbed near the surface).

15. (a) Prevents mixing of the oxygen-rich surface water with the deeper oxygen-deficient water (represents a thermal barrier.)
(b) Organisms (particularly bacteria) living below the thermocline use up much of the available oxygen. Decomposition also uses up oxygen.
16. (a) **Heavy rainfall** or inflow of floodwater from nearby river channels may cause a decline in conductivity.
(b) **Evaporation** from the lake concentrates salts and the conductivity will increase.
17. Physical gradients will govern what organisms will be found and where within a particular area, as determined by the tolerance levels of individual organisms.

Shoreline Zonation (page 289)

1. (a) Exposure time determines what species can extend higher up the shore where the time without submergence is longer. Some species are intolerant of long exposure times, others are very tolerant.
(b) (Any two of): Intensity of wave action, salinity (in pools), temperature (in pools), oxygen level (in pools).
(c) Presence or absence of competing species, presence or absence of predators.
2. Broad bands approximately parallel to the water's edge, formed by distinct assemblages of species.

Habitat (page 290)

1. An organism will occupy habitat according to its range of tolerance for a particular suite of conditions (temperature, vegetation and cover, pH, conductivity). Organisms will tend to occupy those regions where all or most of their requirements are met and will avoid those regions where they are not. Sometimes, a single factor, e.g. pH for an aquatic organisms, will limit occupation of an otherwise suitable habitat.
2. (a) Most of a species population is found in the optimum range because this is the zone where conditions for that species are best; most of the population will select that zone.
(b) The greatest constraint on an organism growth within its optimum range would be competition between it and members of the same species (or perhaps different species with similar niche requirements).
3. In a marginal niche, any of the following might apply:
 - Physicochemical conditions (e.g. temperature, current speed, pH, conductivity) might be sub-optimal and create stress (therefore greater vulnerability to disease).
 - Food might be more scarce or of lower quality/nutritional value.
 - Mates might be harder to find.
 - The area might be more exposed to predators.
 - Resting, sleeping, or nesting places might be harder to find and/or less suitable in terms of shelter or safety.
 - Competition from other better-adapted species might be more intense.

Dingo Habitats (page 291)

1. Densities per 100 km² as follows:
Pack B: 12.8 Pack C: 3.5 Pack D: 9.5
2. (a) Hills (d) Floodplain
(b) Floodplain and hills (e) Hills and floodplain
(c) Floodplain
3. Dingoes show a preference for riverine habitat. This is indicated by the fact that they spend a disproportionate amount of time in riverine compared to the total habitat available (even when riverine habitat is scarce, the packs spend time there). Stony areas are avoided.
4. (a) Dingoes are caught and fitted with radiotransmitters. At set intervals, the signals from individual animals can be recorded and mapped giving a composite picture of movements over a period of time.
(b) 4194
(c) 4 years
(d) A large number of records provides more accurate information about the size and boundaries of the area over which the packs range. Too few records would not clearly indicate the ranges covered.
5. It probably plays some part since the areas with very low kangaroo abundance also have low dingo densities. However other limiting factors in the environment (particularly the availability of suitable riverine habitat) are important. **Note:** High kangaroo abundance will not necessarily equate with high dingo densities if other factors are limiting; there is a trade-off between food availability and other factors (such as suitable habitat).
6. (a) Home ranges are larger in areas where water (and vegetation) are limited (arid regions with no riverine areas). Moist, forested areas (high water availability and vegetation cover) have the smallest ranges.
(b) Areas with poor water supply offer little in the way of vegetation diversity. Habitats end to be rather homogeneous in arid areas.

Ecological Niche (page 293)

1. The (fundamental) **niche** describes the total collection of adaptations that allows an organism to exploit the resources of its habitat according to the lifestyle to which it is fitted. The physical conditions will determine the organism's preferred habitat within a range (according to the law of tolerances).
 2. Competition with other species may prevent the organism from exploiting all resources it is adapted to use. Competition forces species to occupy a **realized niche** that is narrower than their fundamental niche.
 3. Organisms occupying the same habitat and general feeding niche can minimize competition by exploiting:
 - Different times of the day or night (e.g. feeding at dawn or dusk vs feeding during the daylight)
 - Slightly different foods, e.g. specializing to feed on particular types of insect rather than feeding on all insects generally.
 - Living in slightly different regions within the same area, e.g. high in the canopy vs near the forest floor. Similar foods may be available in both places.
- Students may give specific local examples if they wish.

Competition and Niche Size (page 294)

- Interspecific competition describes competition for resources between members of different species, whereas intraspecific competition describes competition for resources between members of the same species. Intraspecific competition tends to broaden niches as scramble competition forces individuals to move outside their optimum resource range. Interspecific competition tends to make niches narrower because it encourages niche differentiation and resource specialization (compartmentation of the available resources) to minimize scramble competition.
- One species (the more 'able' competitor) would do better at the expense of the other (the less able competitor). The less able species would then be pushed into a less favorable area.
 - At different times of the year different foods/mating and nesting sites might be taken by different species, either intensifying or lessening resource overlap (therefore resource competition).
 - If the zone of resource use overlap was increased the breadth of the realized niche of each species would increase because of niche expansion into less favored areas.
- Niche breadth can become broader where a species is an ecological generalist and can exploit a wide variety of habitats, food types, nesting/breeding sites etc. Many pest species are such generalists.

Adaptations to Niche (page 295)

For each of the following the list is not exhaustive, but uses examples given on the diagrams. Note that most adaptations have components of structure, physiology, and behavior (e.g. threat behaviors involve use of structural features. Thermoregulatory physiology involves some behavior etc.). Categories may not be mutually exclusive.

- Common mole adaptations:
 - Structural:** Generally these are adaptations to aid efficient digging and tunneling, assisting survival through protection and effective food gathering. Clawed hindfeet push soil out of the way when digging (improves efficiency). External ear openings are covered by fur to protect them when digging. Short, powerful limbs with efficient lever arrangement of muscles and joints aids rotation-thrust movement in digging. Forefeet powerfully clawed as digging tools. Velvety fur reduces friction when moving through the soil. Fur can lie in either direction so backward movement in tunnel is not hampered. Tubular body shape aids movement underground. Heavily buttressed head and neck makes tunneling easier and more energy efficient.
 - Physiological:** Well developed chemical sense aids location of food. Good sense of hearing.
 - Behavioral:** Solitary and territorial behavior (except when breeding) helps to maintain a viable food supply and reduce aggressive encounters. Sleep and feed underground offering effective protection from predators.
- Snow bunting adaptations:
 - Structural:** large amount of white plumage reduces heat loss, white feathers are hollow and air filled (acting as good insulators).
 - Physiological:** Lay one or two more eggs than

(ecologically) equivalent species further south producing larger broods (improving breeding success), rapid molt to winter plumage is suited to the rapid seasonal changes of the Arctic.

- Behavioral:** feeding activity continues almost uninterrupted during prolonged daylight hours (allowing large broods to be raised and improving survival and breeding success), migration to overwintering regions during Arctic winter (escapes harsh Arctic winter), will burrow into snow drifts for shelter (withstand short periods of very bad weather), males assist in brood rearing (improved breeding success).
- (a)-(f), any six of:
 - Long, mobile ears provide acute detection of sounds from many angles (for predator detection).
 - Long, strong hind legs are adapted for rapid running (for escape from predators).
 - Cryptic/camouflage coloring of fur assists in avoiding being detected by predators.
 - Limb structure facilitates burrowing behavior.
 - High metabolic rate and activity allows rapid response to dangers.
 - Keen sense of smell enables detection of potential threats from predators and from rabbits from other warrens (they are highly territorial).
 - Digestive system suited for coping with microbial digestion of cellulose in the hindgut.
 - European rabbit is active during any time of the day or night, but modifies its behavior around humans to be active around dusk and dawn (crepuscular).
 - Lives in groups of highly organized social structure (cooperative defense) and reduced competition between rabbits of the same warren.
 - Burrows into ground to provide nesting sites, and shelter from physical conditions and predators.
 - Thumps the ground with hind legs to warn others in the warren of impending danger.
 - Structural (larger, stouter body conserves heat).
 - Physiological (concentrated urine conserves water).
 - Behavioral (move to favorable sites).
 - Physiological (higher photosynthetic rates and water conservation).
 - Structural (reduction in water loss).
 - Behavioral and physiological (hibernation involves both a reduction in metabolic rate and the behavior necessary to acquire more food before hibernation and to seek out an appropriate site).
 - Behavioral (increase in body temperature).

Ecological Succession (page 297)

- Primary succession** refers to the changes to a community when a bare area (e.g. rocky slope, exposed slip, new island) is colonized first by pioneer (colonizing) species and then by successive seral stages, until a climax community is reached.
Secondary succession refers to the community changes occurring after the interruption of an established climax community (e.g. logging, pasture reverting to bush).
- A primary succession rarely follows the classic colonization sequence because, in reality, the rate at which plants colonise bare ground and the sequence of plant communities that subsequently develop are influenced by the local conditions and the dispersal

mechanisms of plants in the surrounding region.

3. (a) Lichens, followed by mosses and liverworts.
(b) Lichens do not need soil and can tolerate extreme physical conditions (but not pollution). They produce a more favorable environment for the mosses and liverworts that colonize later.
4. Catastrophic events in a rainforest include (any one of): cyclones, fire, slips or landslides, floods, lahars, droughts, and windstorms.
5. (a) Selective logging causes gaps in the canopy with the loss of the large trees. This results in a chance for new seedlings to gain more light and grow up. These seedlings may be the same or different from the species that was/were removed. Forest composition is changed by becoming temporarily more open, with a loss of the dominant large trees.
(b) Selective logging is considered (by some) to be preferable to clear felling because there is still a favorable environment in which seedlings can mature. Canopy gaps are created naturally by windfalls; selective logging is said to mimic this, so the gaps created *may* be beneficial for forest diversity and regeneration. Clear felling, in contrast, removes all forest from the area leaving an environment unfavorable for the regeneration of existing forest species but favorable for weeds.
Note: There is a good deal of opposition to this view by some conservationists. While considered preferable to clear-felling, selective logging may still do lasting damage to forest structure and diversity.
6. (a) A **deflected succession** refers to a succession that is deflected from its natural course by human intervention. A climax community (a plagioclimax) develops that is different from the one that would have developed if the intervention had not occurred.
(b) Many human-modified landscapes (e.g. agricultural lands, grasslands, woodlands) are managed (by burning, grazing, mowing) with the express purpose of preventing the establishment of a natural climax community. These communities are quite distinct from those that would naturally develop if the land were left alone.

Energy Inputs and Outputs (page 300)

1. Producers convert energy received from an inorganic source (usually sunlight) into a form that is accessible to consumer levels. Consumers depend on the energy stored in the chemical bonds of biological molecules (the fats, proteins, and carbohydrates of plant and animal tissues). They too transfer energy to other levels, but energy is lost with each transfer.
2. In a grazing food web, energy moves from producers (plants) to primary consumers (herbivores) and then to secondary consumers (carnivores). This chain of energy transfer can continue several times, but eventually ends. All these consumer groups provide energy to decomposer levels. In a detrital food web, producers provide energy as dead plant material, and the primary consumers are decomposer microorganisms such as bacteria and fungi. Energy flows back and forth between decomposers and detritivores but herbivores and carnivores do not feature.

3. Detritivores consume (ingest) detritus (decomposing organic material), and in doing so they speed up decomposition by increasing the surface area available to decomposer bacteria. Decomposer organisms (bacteria and fungi) also use detritus as an energy source but digestion is extracellular (enzymes are secreted in fungi or bound to the cell surface in bacterial cells). These enzymes break down the detritus into constituent molecules for absorption so the breakdown is more complete than is the case with detritivores.

Food Chains and Webs (page 301)

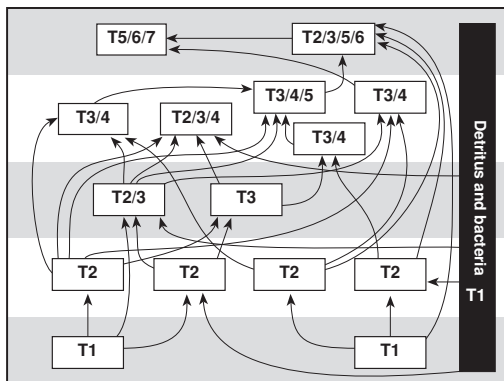
1. (a) Each successive trophic level has less energy.
(b) Energy is lost by respiration as it is passed from one trophic level to the next.
2. A food chain comprises a sequence of organisms, each of which is a source of food for the next. Food chains in ecosystems are organised according to trophic levels; the feeding levels that energy passes through as it proceeds through the food chain. Organisms are assigned a category according to the trophic level they occupy. Producers form the first trophic level, 1st order consumers (primary consumers) eat producers (i.e. they are herbivores), 2nd order consumers (secondary consumers) eat herbivores (i.e. they are carnivores) etc. Organisms may occupy more than one trophic level depending on their diet. Detritivores and decomposers obtain energy from all other trophic levels and are therefore not assigned a trophic level.
3. (a)-(e) Some food chain examples as below (there are others possible):
 - Algae → zooplankton → diving beetle
 - Algae → zooplankton → stickleback → pike
 - Macrophyte → great pond snail → herbivorous water beetle → stickleback → pike
 - Algae → mosquito larva → *Hydra* → dragonfly larva → carp → pike
 - Macrophyte → carp → pike
 - Macrophyte → herbivorous water beetle → carp → pike
 - Algae → zooplankton → *Asplanchna* → leech → dragonfly larva → carp → pike
4. Food web solution at the top of the next page. Trophic levels are indicated by the letter T and the number(s) of the level(s) occupied. Note: the trophic level a species occupies will depend on the trophic position of its food items. For example, the carp occupies several different trophic levels, since it feeds on macrophytes, and on both primary and tertiary consumers. The tertiary consumers that the carp eats will also be feeding at a number of different levels, hence the complexity of food webs and the difficulty in accurately representing them in diagrams.

Energy Flow in an Ecosystem (page 303)

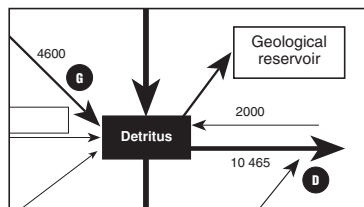
1. (a) 14 000 (c) 35
(b) 180 (d) 100

Constructing a lake foodweb:

For reasons of space, the names have been omitted from this solution but the relative positions of each organism is as presented in the manual. Trophic levels are indicated by the letter T and the number(s) of the level(s) occupied. Note: the trophic level a species occupies will depend on the trophic position of its food items. For example, the carp occupies several different trophic levels, since it feeds on macrophytes, and on both primary and tertiary consumers. The tertiary consumers that the carp eats will also be feeding at a number of different levels, hence the complexity of food webs and the difficulty in accurately representing them in diagrams.



2. Solar energy
3. A. Photosynthesis
B. Eating/ feeding/ingestion
C. Respiration
D. Export (lost from the ecosystem to another)
E. Decomposers and detritivores feeding on other decomposers and detritivores
F. Radiation of heat to the atmosphere
G. Excretion/egestion/death
4. (a) $1\,700\,000 \div 7\,000\,000 \times 100 = 24.28\%$
(b) It is reflected. Plants appear green because those wavelengths are not absorbed. Reflected light falls on other objects as well as back into space.
5. (a) $87\,400 \div 1\,700\,000 \times 100 = 5.14\%$
(b) $1\,700\,000 - 87\,400 = 1\,612\,600$ (94.86%)
(c) Most of the energy absorbed by the producers is **not** used in photosynthesis. This excess energy which is not fixed is lost as heat (although the heat loss component **before** the producer level is not usually shown on energy flow diagrams). **Note:** Some of the light energy that is absorbed through accessory pigments such as carotenoids widens the spectrum that can drive photosynthesis. However, much of accessory pigment activity is associated with photoprotection; they absorb and dissipate excess light energy that would otherwise damage chlorophyll.
6. (a) 78 835 kJ
(b) $78\,835 \div 1\,700\,000 \times 100 = 4.64\%$
7. (a) Decomposers and detritivores
(b) Transport by wind or water to another ecosystem (e.g. blown or carried in air/stream/river/ocean currents).
8. (a) Energy remains locked up in the detrital material and is not released.
(b) Geological reservoir:



(c) Oil (**petroleum**) and **natural gas**, formed from the buried remains of marine plankton. **Coal** and **peat** are both of plant origin; peat is partly decomposed, and coal is fossilized.

9. (a) $87\,400 \rightarrow 14\,000$: $14\,000 \div 87\,400 \times 100 = 16\%$
(b) $14000 \rightarrow 1600$: $1600 \div 14\,000 \times 100 = 11.4\%$
(c) $1600 \rightarrow 90$: $90 \div 1600 \times 100 = 5.6\%$

Ecological Pyramids (page 305)

1. (a) Number pyramid: Numbers of individual organisms at each trophic level.
(b) Biomass pyramid: Weight (usually dry weight) of all organisms at each trophic level.
(c) Energy pyramid: Energy content of all organisms at each trophic level.
2. Biomass or energy pyramids usually more accurately reflect the energy available to the next trophic level than pyramids of numbers. Pyramids of numbers can be misleading because a small number of producers may represent a large amount of biomass or energy.
3. Producers include the large trees. These have a large biomass and energy content per individual.
4. (a) $8690 \rightarrow 142 = 8548 \text{ kJ} = 1.6\%$
(b) $142 \rightarrow 12 = 130 \text{ kJ} = 8.5\%$
(c) Energy passed on from producers to primary consumers is less than the expected 10% because a lot of energy is diverted to the decomposers.
(d) Decomposers
(e) In a plankton community, turnover times (generation times of organisms) are very short and there is a lot of dead material both in the water and on the bottom. This provides a rich energy source to support a large biomass of decomposers.

5. The algae are reproducing at a high rate, but are being heavily cropped by the larger biomass of zooplankton.

The Nitrogen Cycle (page 307)

- (a)-(e) any of:
 - Decomposition or decay of dead organisms, to ammonia by decomposer bacteria (ammonification).
 - Nitrification of ammonium ions to nitrite by nitrifying bacteria such as *Nitrosomonas* ($\text{NH}_4^+ \rightarrow \text{NO}_2^-$)
 - Nitrification of nitrite to nitrate by nitrifying bacteria such as *Nitrobacter* ($\text{NO}_2^- \rightarrow \text{NO}_3^-$)
 - Denitrification of nitrate to nitrogen gas by anaerobic denitrifying bacteria such as *Pseudomonas* ($\text{NO}_3^- \rightarrow \text{N}_{2(g)}$)
 - Fixation of atmospheric nitrogen to nitrate by nitrogen fixing bacteria such as *Azotobacter* and *Rhizobium* ($\text{N}_2 \rightarrow \text{NO}_3^-$)
 - Fixation of atmospheric nitrogen to ammonia by nitrogen fixing cyanobacteria ($\text{N}_2 \rightarrow \text{NH}_3$)
- (a) Oxidation of atmospheric nitrogen by lightning.
(b) Nitrogen fixation (by bacteria).
(c) Production of nitrogen fertiliser through the Haber process.
- Denitrification
- The atmosphere.
- Nitrate.
- Any one of: amino acids, proteins, chlorophyll.
- Animals ingest food (plants or other animals); they are heterotrophic.
- Leguminous material is high in nitrogen. Ploughing it in replenishes soil nitrogen and reduces the need for additional nitrogen fertiliser when growing non-leguminous crops subsequently.
- Human intervention in the nitrogen cycle by (a)-(e) in any order:
 - Addition of nitrogen fertilisers to the land. This practice supplies inorganic nitrogen, as nitrate, for plant growth, but has the disadvantage that any excess nitrogen, not absorbed by plants, may enter and pollute ground water and water bodies.
 - Industrial physical-chemical fixation of nitrogen (through the Haber process) combines hydrogen and nitrogen to ammonia, which can be used to manufacture inorganic nitrogen fertilisers. This is an industrial process, which requires high temperatures and pressures and uses a large amount of energy. The effects of applied inorganic nitrogen are outlined in (a) above.
 - Genetic modification of crop plants so that they can fix nitrogen. The effect of this is to increase the range of crop plants capable of growing on nitrogen deficient soils. Potentially, this could make a beneficial contribution to soil fertility.
 - Large-scale, assisted composting produces nitrogen rich organic fertiliser which has the effect of improving soil fertility and structure. This has beneficial effects in reducing the amount of inorganic nitrogen fertiliser that must be applied.
 - Burning and harvesting removes nitrogen from the land and releases nitrogen oxides into the atmosphere.

- Discharge of effluent (particular animal waste) into waterways enriches water bodies and leads to localised pollution and eutrophication.
- Irrigation can accelerate loss of nitrate from the soil by increasing the rate at which nitrates are washed out of the soil into ground water.

The Carbon Cycle (page 309)

- Arrows can be added for the points (a)-(d) as follows:
 - Dissolving of limestone by acid rain: arrow from the limestone layer to atmospheric CO_2 .
 - Release of carbon from the marine food chain: arrows (labeled **respiration**) from marine organisms (shark, algae, small fish) to atmospheric CO_2 .
 - Mining and burning of coal: arrow from the coal seam to atmospheric CO_2 .
 - Burning of plant material: arrow (**combustion**) from the trees and/or grassland to atmospheric CO_2 .
- (a) Coal: Plant material trapped under sediment in swampy conditions millions of years ago.
(b) Oil: Marine plankton rapidly buried in fine sediment millions of years ago.
(c) Limestone (also chalk = fine limestone): Shells of molluscs, skeletons of coral and other marine organisms with skeletons of calcium carbonate piled upon seabeds and compressed.
- Respiration (stepwise oxidation of glucose) and combustion (rapid oxidation of organic substances accompanied by heat). Both involve the release of CO_2 .
- (a)-(d) in any order: Atmosphere, coal, limestone, oil and natural gas.
- Carbon would eventually be locked up in the bodies (remains) of dead organisms. Dead matter would not rot. Possible gradual loss of CO_2 from the atmosphere.
- (a) Photosynthesis (b) Respiration
- (a) Dung beetles: Bury the cow manure and the larvae feed on it. Burying the dung makes it available to decomposers in the soil. The beetle larvae reprocess the dung, using it as a food source. It therefore re-enters the trophic system.
(b) Termites: Digest the cellulose in plant material, breaking it down and freeing up the carbon back into the ecosystem.
(c) Fungi: Break down dead material, utilizing it as food and converting it into the fungal body. This makes it available to reenter the food chain.
- (a) Humans deplete these fossil fuel reserves through mining (fossil fuels provide readily available energy).
(b) The burning of fossil fuels increases the amount of carbon dioxide in the atmosphere, contributing to the rise in global temperatures. Burning also increases levels of air pollution.
(c) Minimizing fossil fuels use through the use of alternative, environmentally clean sources of energy (solar energy, wind energy). Making sure that when fossil fuels are burnt, that combustion is as clean (complete) as possible, to minimize pollution.

The Water Cycle (page 311)

- (a) Surface runoff (b) Ground-water flow
- (a)-(c) any of the following, in any order:
 - Humans withdraw water from ground-water storage, rivers, and lakes. It may be used to supply domestic or personal use, or for irrigation. Consequently it may become depleted in specific areas or its normal destination altered.
 - Humans divert water and alter natural flows through damming and controlled flows. This alters the normal balance of seasonal water movements.
 - Humans may use water courses or water bodies for disposal of waste, polluting it and making it unsuitable for other organisms.
 - Humans clear vegetation, reducing the amount of water re-entering the atmosphere and being returned to the land via precipitation.
- The oceans.
- In descending order of magnitude: Snow and ice (in ice sheets and glaciers), ground-water, lakes, soil, atmosphere, rivers.
- Plants lose a vast amount of water through transpiration. This is returned to the atmosphere where it condenses and then precipitates back to the land.

Features of Populations (page 313)

- (a) One of the following:

Population growth rate: If this increases (or decreases) from one time interval to the next, it indicates that the population is probably also increasing (or decreasing). **Note:** The intrinsic rate of population increase (r_{max}) should be distinguished from population growth rates that account for the increasing number of individuals in the population (r_N). The intrinsic population growth rate is a characteristic value for each species but r_N can increase rapidly as more and more individuals add to the population increase (giving an exponential curve). Population growth rates account for birth and death rates but do not usually account for losses and gains through migration, which are usually assumed to be equal.

Total abundance: If this increases (or decreases) from one time interval to the next, it indicates that the population is also increasing (or decreasing).

Mortality rate: If this is increasing from one time interval to the next, it indicates that the population may be decreasing (you must also account for other sources of population change).

Birth rate & population fertility: If these increase from one time interval to the next, they indicate that the population may be increasing (you must also account for other sources of population change).

Age structure: A population dominated by young individuals is usually increasing. A population dominated by old (especially post-reproductive) individuals is usually decreasing.
- (b) One of the following:

Distribution: A very clumped distribution may indicate that only some parts of the environment are suitable for supporting individuals.

Population growth and birth rates: If these are low or declining it may indicate an inability of the environment to support the population density.

Mortality rates: If these are very high or increasing it may indicate an inability of the environment to support the present population density.

- (a) **Measurable attributes:** Density, distribution, total abundance, sex ratios, migration (sometimes difficult). In some cases, depending on the organism, also age structure and population fertility.
(b) **Calculated attributes:** Population growth rate, natality (birth rate) and mortality (death rate).
- (a) Population sampling of an endangered species allows us to determine (any of): How fast a population is growing (if at all); the age and sex structure of the population (i.e. is it dominated by young or very old, non-reproductive, individuals); population abundance, density and distribution in different areas (indicating habitat preference and suitability); sources of mortality (predation, disease, starvation etc.); population fertility (reproductive state). This type of information allows more informed decisions to be made about the current status of the population and how best to manage it (through habitat restoration or captive breeding for example).
(b) Population sampling of a managed fish species allows us to determine the population growth rate. This is critical to establishing the level of fishing that can be supported by the population (the sustainable harvest) without irreversible population decline. The growth rate is calculated taking into account population abundance, and birth and death rates. Sustainable harvest can be built into the equation as one of the (controllable) sources of mortality.

Density and Distribution (page 314)

- (a) Resources such as food and shelter are not usually spread through the environment in an even manner. Organisms will clump around these resources.
(b) Some organisms group together for protection from the physical environment or from predators. They may also group together for mating and reproduction. Clumped distributions may also result from the method of dispersal (e.g. in plants, vegetative spread (as opposed to dispersal by seeds) leads to clumping around the parent plant).
- Territorial behavior.
- Resources in the environment are limited but are distributed uniformly.
- (a) **Clumped:** Many marine gastropods, colonial birds (seasonally), many mammals that exhibit grouping/herd behavior, schooling fish, colonial insects, many other invertebrates such as coral, some plants with limited dispersal.
(b) **Random:** Weed plants with effective dispersal method, shellfish on sand or mud substrate.
(c) **Uniform:** Territorial organisms, monoculture plantings (e.g. crops, timber plantations)

Population Regulation (page 315)

- Density dependent factors**, such as disease, parasitic infestation, competition, and predation have an increasing effect on population growth as the density of the population increases; their effects are exacerbated at high population densities because they

are driven in part by the number of organisms present. **Density independent factors**, such as flood, fire, and drought have a controlling effect on population size and growth that is independent of the population density. The severity of the impact on the population is not correlated with the density of the population.

- When population density is low, individuals are well spaced apart. This can reduce stress between individuals (improving the resistance to diseases) as well as making the transmission of the pathogen more difficult. Crowded populations are more susceptible to epidemics of infectious disease.
- (a) Density dependent factor: Predation (e.g. by ladybird beetles), competition with other aphids for position on the best part of the plant to feed.
(b) Density independent factor: Temperature (drop in temperature in autumn months in cooler climates causes the population to crash).

Population Growth (page 316)

- (a) Mortality: Number of individuals dying per unit time.
(b) Natality: Number of individuals born per unit time.
(c) Immigration: Individuals moving into the population.
(d) Emigration: Individuals moving out of the population.
(e) Net migration rate: Net change in population size per unit time due to immigration and emigration.
- (b) A declining population: $B + I < D + E$
(c) An increasing population: $B + I > D + E$
- Rate of change for USA: $+ 1.0$
Rate of change for Mexico: $+ 3.3$
- (a) Birth rate = $14 \text{ births} \div 100 \text{ total number of individuals} \times 100\% = 14\% \text{ per year}$
(b) Net migration rate = $2\% \text{ per year}$
(c) Death rate = $20\% \text{ per year}$
(d) Rate of population change: birth rate – death rate + net migration rate = $14 - 20 + 2 = -4\% \text{ per year}$
(e) The population is **declining**.

Life Tables and Survivorship (page 317)

- In some undeveloped countries, with high reproductive rates but poor infant survival (high infant mortality), the curve may resemble a modified Type III curve. Even though there is parental care, this does not offset the losses of young to starvation and disease.
- They produce vast quantities of eggs/offspring.
- Parental care is highly developed and for a longer time than for most Type II and all Type III species.
- The majority of deaths occur in the first year.

Population Growth Curves (page 318)

- As population numbers increase, the resistance of the environment (to further population increase) increases. This constrains the population to keep to a size that the environment can support at any one time.
- Environmental resistance refers to all the limiting factors that together act to prevent further population increase (achievement of intrinsic rate of population increase, r_{max}).

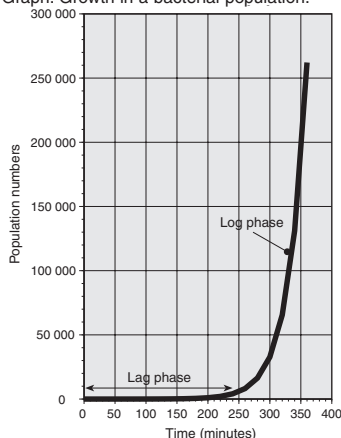
- (a) The maximum population size (of a species) that can be supported by the environment.
(b) Carrying capacity limits population growth because as the population size increases, population growth slows (when $N = K$ population growth stops). **Note:** For those interested in extension in this area, the effect of K on population growth is defined by the mathematical expression of logistic growth. This is covered in many, more advanced, biology texts.
- (a) A new introduction increases exponentially (or nearly so) in a new area because its niche in that environment is unexploited up to that point. Resources (food, space, shelter etc.) are plentiful and readily available. The population rapidly increases, then slows as the population encounters environmental resistance.
(b) Population numbers would fluctuate around some relatively stable population size that equates to what the environment can support (the carrying capacity).
- Introduced grazing species can lower the carrying capacity of environments by reducing the ability of the environment to recover from the impacts of grazing.
Note: High population numbers and high stocking levels (e.g. sheep in Australia, cattle in sub-Saharan Africa) lead to overgrazing and trampling of the soil. Soil is lost through erosion and desirable plant species are then replaced by (weed) species that can survive the grazing pressure. Native consumers tend not to overexploit the environment in this way because they have different patterns of resource use and population growth.

Growth in a Bacterial Population (page 319)

1. Tabulated figures below.

Min	No.	Min	No.	Min	No.
0	1	140	128	280	16 384
20	2	160	256	300	32 768
40	4	180	512	320	65 536
60	8	200	1024	340	131 072
80	16	220	2048	360	262 144
100	32	240	4096		
120	64	260	8192		

2. Graph: Growth in a bacterial population:



3. 1 hour: 8 3 hours: 512 6 hours: 262 144
4. Exponential curve (logarithmic growth).
5. The graph would flatten out as the bacteria enter the stationary growth phase. Ultimately, in the death phase the slope of the graph would become negative.

r and K Selection (page 320)

- r* refers to the maximum reproductive potential of an organism and *r*-selected species are those with a high intrinsic capacity for population increase. *K* refers to the carrying capacity of the environment and *K*-selected species exist near this point of equilibrium with the environment.
- r*-selected species are **opportunists** because they are poor competitors and must continually invade new areas in order to gain the advantage of their high reproductive potential. Examples include algae, bacteria, rodents, many insects and most annual plants.
- K*-selected species are also called **competitor species** because they are challenged in competitive environments to use available resources more efficiently and thereby compensate for their lower reproductive potential. Examples include most larger mammals, birds of prey, and large, long-lived plants.
- Many *K*-selected species are endangered because their lower reproductive potential makes it difficult for them to recover stable, viable populations following loss (of numbers or suitable environments).

Population Age Structure (page 321)

- (a) 3:1
(b) Other factors besides changes in age structure can affect population growth, e.g. sex ratios, population fertility, and migration.
- Over a short duration, the large cohort of prereproductive individuals will reach reproductive age and the population will continue to grow. Even if the rate of population growth continues to slow it will take several generations before the 'bulge' of reproductive individuals moves into the postreproductive phase.
- (a) Mortality
(b) Higher proportion of smaller/younger fish.
- (a) 3 years (b) 5 years (c) 8 years
- (a) Gray face: It has palms of all sizes and therefore all ages are represented.
(b) Golf course: No small (=young) plants are represented.
- The population will age, with the established palms growing taller, and no new palms becoming established. Eventually these older palms will die with no replacement (unless there is a planting program).
- Not all organisms (e.g. plants, fish) grow at the same rate. Size may depend on the quality and quantity of food supply. Some seasons may produce more growth than others.
- If the age structure in the short-medium term shows a trend to smaller/younger age classes, then harvesting

pressure is too severe. If this continues, there will be few individuals of reproductive age and, consequently, a decline in the harvestable stock (population size).

Species Interactions (page 323)

- Mutualism** between a ruminant and its gut microflora: In this mutualistic relationship both parties benefit (in this case, more than two species are involved, as several microbial species are mutualistic with the ruminant). Volatile fatty acids, released as a result of microbial digestion of cellulose, provide a source of energy for the ruminant (e.g. cow, goat, sheep, deer). There is also some digestion of the microbes themselves and this provides protein. The microorganisms (usually a species specific combination of bacteria and ciliates) gain an oxygen free, nutrient rich environment at the optimum growing temperature.
 - Commensalism** between shark and remora: In this relationship, the commensal (the remora) benefits by being transported in relative safety with very little energy cost to itself. The shark (various species have commensal remoras) is neither benefited nor disadvantaged by the remora's presence (although it is possible remoras increase drag to an extent).
 - Parasitism** between tapeworm and humans: In this relationship, the tapeworm parasite (*Taenia solium*) gains by having a safe, equable environment in which to live and produce proglottids (reproductive segments containing eggs), and by having a readily available supply of nutrients from the digested slurry in the host's gut. Even the proglottids are specialized for the selective absorption of digested food. The human host is harmed by the loss of nutrients to the parasite, and by gut irritation and potential infection.
 - Parasitism** between a cat flea and its host: In this relationship, the flea (*Ctenocephalides* spp.) is the parasite and gains by having a relatively safe environment at the right temperature in which to live and produce eggs, and by having a readily available supply of nutrients in the form of the cat's blood. The cat host (*Felis domestica*) is harmed to an extent by blood loss, but more by skin irritation and infection (including flea allergy dermatitis), and by the transmission of other parasites, such as tapeworms, which are transmitted by the flea.
- Interactions:

B Description		
(a) +	Both species benefit.	
(b) 0	Species A benefits, no effect on species B.	
(c) +	Species A (the host) is harmed, species B (the parasite) benefits.	
(d) -	No effect on species A, species B is harmed.	
(e) +	Species A (prey) is harmed, species B (the predator) benefits.	
(f) -	Both species (competitors) are harmed.	
(g) -	Species A (herbivore) benefits, species B (plant) is harmed.	
(h) -	Species A benefits, species B is harmed.	
	Species A is unaffected, species B is harmed.	
- Identifying examples of species interactions:

Term	A	B
(b) Exploitation	+	-
(c) Antibiosis (or amensalism)	0	-
(d) Competition	-	-

- | | | |
|------------------|---|---|
| (e) Commensalism | + | 0 |
| (f) Mutualism | + | + |

Predator-Prey Strategies (page 325)

- Active concealment from view (such as in a burrowing animal, e.g. rabbit, earthworm); rolling into a ball to expose prickles (hedgehog); erecting spines (porcupine), spaying noxious fluid (e.g. vegetable bug).
- Any of many possible examples:
 - Cooperative (group) hunting in pelicans, lions.
 - Stealth, lying in wait for an ambush (angler fish).
 - Tool use in chimpanzees, otters.
- By advertising the fact that they are unpalatable, predators quickly learn to associate the coloration with distastefulness. When seen, they are not mistaken for a palatable species and they are left alone.
- Deceptive markings such as fake eyes can momentarily deceive predators into thinking that they are faced with a larger animal than they really are. This may give time for the prey to escape or may result in the predator attacking a non-vital part of the prey.
- Batesian mimicry benefits the mimic because predators universally avoid attacking animals with the same warning coloration, whether they are poisonous or not.
- Freezing**, i.e. lying low to the ground and remaining very still, can enable a prey species (e.g. rabbit, hare, deer, various ground-dwelling birds) to avoid detection.

Predator-Prey Interactions (page 326)

- Usually between about 3 and 7 years (especially for pronounced peaks), although sometimes as great as a full 10 year cycle. Note that peaks often appear to be superimposed or the lynx peaks appear to be ahead of hare peaks. Remember that the lynx are responding to the earlier peaks in hare abundance.
 - Lynx are top predators, with longer reproductive times and generation times than hares. When the hare populations increase there is a considerable time delay before this increase in available food is translated into higher population growth rates in lynx (birth rates must increase, usually mortality rates must also fall). Likewise, a fall in hare numbers takes some time to be registered by a decline in lynx population growth rate.
- Hares are the principal food item for lynx in this system; there is little opportunity for prey switching (few alternative prey). The lynx cycles follow those of the hares closely with a similar periodicity.
- When the supply of palatable food declines, birth rates decline (adults are less well nourished and litters are smaller) and the mortality rate increases (more deaths due to starvation and disease). **Note:** Population growth rates depend on both birth and death rates: ($r = b - d$). When birth rates decline and mortality increases, r becomes negative and the population goes into decline.
 - High mortality (losses from the population) can be sustained by species such as rodents and lagomorphs as long as they can maintain their intrinsically high birth rates. Declines in palatable food adversely affects their ability to do this.

Intraspecific Competition (page 327)

- Individual growth rate:** Intraspecific competition may reduce individual growth rate when there are insufficient resources for all individuals (Examples: tadpoles, *Daphnia*, many mammals with large litters). **Note:** Individuals compete for limited resources and growth is limited in those individuals that do not get access to sufficient food.
 - Population growth rate:** Intraspecific competition reduces population growth rate. Examples as above. **Note:** Competition intensifies with increasing population size and, at carrying capacity, the rate of population increase slows to zero.
 - Final population size:** Intraspecific competition will limit population size to a level that can be supported by the carrying capacity of the environment. **Note:** In territorial species, this will be determined by the number of suitable territories that can be supported.
- They reduce their individual growth rate and take longer to reach the size for metamorphosis.
 - Density dependent.
 - The results of this tank experiment are unlikely to represent a real situation in that the tank tadpoles are not subject to normal sources of mortality and there is no indication of long term survivability (of the growth retarded tadpoles). **Note:** At high densities, many tadpoles would fail to reproduce and this would naturally limit population growth (and size) in the longer term.
- Reduce intensity of intraspecific competition by:
 - Establishing hierarchies within a social group to give orderly access to resources.
 - Establishing territories to defend the resource within a specified area.
- Carrying capacity might decline as a result of unfavorable climatic events (drought, flood etc.) or loss of a major primary producer (plant species).
 - Final population size would be smaller (relative to what it was when carrying capacity was higher).
- Territoriality** is a common consequence of intraspecific competition in mammals and birds. In any habitat, resources are limited and only those with sufficient resources will be able to breed. This is especially the case with mammals and birds, where the costs of reproduction to the individual are high relative to some other taxa. Even though energy must be used in establishing and maintaining a territory, territoriality is energy efficient in the longer term because it gives the breeding pair relatively unchallenged access to resources. As is shown in the territory maps of golden eagles and great tits, territories space individuals apart and reduce intraspecific interactions. The size of the territory is related to the resources available within the defended area; larger territories are required when resources are poorer or widely dispersed. As is shown by the great tit example, when territory owners are removed, their areas are quickly occupied by birds previously displaced by competition.

Interspecific Competition (page 329)

- The two species have similar niche requirements (similar habitats and foods). Red squirrels once occupied a much larger range than currently. This range has contracted steadily since the introduction of the

grays. The circumstantial evidence points to the reds being displaced by the grays.

- The grays have not completely displaced the reds. In areas of suitable coniferous habitat, the reds have maintained their numbers. In some places the two species coexist. **Note:** It has been suggested that the reds are primarily coniferous dwellers and extended their range into deciduous woodland habitat in the absence of competition.
- Habitat management allows more effective long term population management *in-situ* (preferable because the genetic diversity of species is generally maintained better in the wild). Reds clearly can hold their own in competition with grays, provided they have sufficient resources. **Enhancing the habitat** preferred by the reds (through preservation and tree planting), assists their success as a competing species. Providing **extra suitable food plants** also enables the reds to increase their breeding success and maintain their weight through winter (thus entering the breeding season in better condition).
- Other conservation strategies to aid red squirrel populations could include (any of): Captive breeding and release of reds into areas where they have been displaced, control/cull of gray squirrels (particularly in habitats suitable for reds), transfer of reds from regions where populations are successful to other regions of suitable habitat, supplementary feeding prior to the breeding season, public education to encourage red squirrels over grays.
- (a) A represents the **realized niche** of *Chthamalus*.
(b) When *Balanus* is removed from the lower shore, the range of *Chthamalus* extends into areas previously occupied by the *Balanus*; *Balanus* normally excludes *Chthamalus* from the lower shore.
- Features will depend on the example chosen. Typical examples for two species that are proving to be invasive in many countries worldwide are described:

- Mallard duck (*Anas platyrhynchos*) (a)-(b) any of:
- Clutch size is relatively large compared with many other duck species.
 - Mallards are sexually aggressive and are capable of interbreeding with several native duck species where their ranges come to overlap (gray ducks in New Zealand, American black duck, the Florida mottled duck, and the endangered Hawaiian duck).
 - Mallards bully native duck species in competition for food and nest sites.
 - Mallards are adaptable in different environments.
- Mosquito fish (*Gambusia affinis*) (a)-(b) any of:
- Prolific breeders in many diverse environments.
 - Aggressive competitors for food.
 - Generalist feeders, and will prey on the eggs and larvae of native fish and frogs.
 - Reproductive strategies tuned to maximizing reproductive output. Females are able to store sperm for extended periods and colonize environments without needing to meet a mate there.

Niche Differentiation (page 331)

- (a) Different species may exploit different microhabitats within the ecosystem (e.g. tree trunks, leaf litter, lower or upper canopy).

(b) Different species may exploit the same resources but at different times of the day or year.

- Intraspecific competition is more intense (than interspecific competition) because individuals of the same species (conspecifics) are competing for exactly the same resources in the environment. There is very little, if any, opportunity for niche differentiation.
- Damselfish might reduce competition by (any of): occupying different positions on the reef, having different activity patterns, occupying different microhabitats (e.g. different coral types), specializing in food types in a restricted area vs generalized feeding over a wider area.

The New Tree of Life (page 333)

- The argument for the new classification as three domains is based on the fact that the genetic differences between the Bacteria and the Archaea are at least as great as between the Eukarya and the Bacteria. In other words, the traditional scheme does not accurately reflect the true evolutionary (genetic) relationship between the three groupings.
- Any one of:
 - The eukaryote groups are given much less prominence, reflecting the true diversity of the prokaryote groups.
 - The Archaea have been separated out as distinct from other bacteria in order to reflect their uniqueness and indicate their true relationship to eukaryotes and to other prokaryotes.
- The six kingdom classification scheme splits the prokaryotes into the kingdoms Eubacteria and Archaeobacteria. These taxa are the same as two of the domains in the three domain classification system.

New Classification Schemes (page 334)

- (a) Morphology recognizes the importance of physical features in distinguishing between groups of organisms (it is a simpler and more familiar operation). It also recognizes the amount of morphological change that occurs in species after their divergence from a common ancestor.
(b) Biochemical evidence produces phylogenies that more correctly represent the true evolutionary relationships between groups (taxa). **Note:** Phylogenies produced this way may be more difficult to interpret and apply and may not recognise morphological changes occurring after divergence from a common ancestor.
- Biochemical evidence compares DNA and proteins between species and provides a more direct measure of common inheritance. **Teacher's note:** For some species, biochemical evidence has shown that earlier phylogenies were in error. Sometimes (as in the case of primates) the earlier phylogenies reflected the human view of their own position in the phylogeny. Morphological similarities can arise through convergent evolution in unrelated groups. Biochemical evidence is not clouded by this type of adaptive morphology.

3. (a) Pongidae

(b) Hominidae

Features of the Five Kingdoms (page 340)

- 1. Prokaryotae:** Lack nuclei and the organized chromosomes typical of eukaryotes. Some genetic material carried on plasmids. Small (70S) ribosomes but lack membrane-bound organelles. Most have a cell wall containing peptidoglycan (unique to bacteria). Divide by binary fission. Cell wall may be associated with a glycocalyx (capsule or slime layer). As a taxon, show a diversity of nutritional modes and lifestyles.
- 2. Protista:** Unicellular or simple multicellular eukaryotes. A diverse group of organisms, many of which are not related phylogenetically. Includes animal-like organisms such as protozoans and plant-like photosynthetic algae.
- 3. Fungi:** Eukaryotic unicellular or multicellular organisms. Heterotrophic and lack chlorophyll. Saprophytes, parasites, or symbionts. Rigid cell walls of chitin. Nutrition always absorptive. Typical organizational unit in filamentous forms is the hypha. Sexual/asexual reproduction involving spores.
- 4. Plantae:** Multicellular eukaryotes, the large majority being photosynthetic autotrophs with chlorophyll. Clearly defined cellulose cell walls. Food stored as starch (and lipid). Primarily sexual reproduction with cycles of alternating haploid and diploid generations.
- 5. Animalia:** Heterotrophic, multicellular eukaryotes. Lack a cell wall and have a blastula stage during development. Further characterization of animal taxa is based on body symmetry, type of body cavity (coelom), and internal and external morphology.

Features of Microbial Groups (page 341)

- 1. Prokaryotae features:** Lack nuclei and the organized chromosomes typical of eukaryotes. Some genetic material carried on plasmids. Small (70S) ribosomes but lack membrane-bound organelles. Most have a cell wall containing peptidoglycan (unique to bacteria). Divide by binary fission. Cell wall may be associated with a glycocalyx (capsule or slime layer). As a taxon, show a large diversity of nutritional modes and lifestyles.
- 2. Protista features:** Unicellular or simple multicellular eukaryotes. A diverse group of organisms, many of which are not related phylogenetically. Includes animal-like organisms such as protozoans and plant-like photosynthetic algae.
- 3. Microfungi features:** Eukaryotic unicellular or microscopic multicellular organisms. Like all fungi, heterotrophic and lack chlorophyll. Nutrition is always absorptive. Saprophytes, parasites, or symbionts. Rigid cell walls of chitin. Typical organizational unit in filamentous forms is the hypha. Sexual/asexual reproduction involving spores.

Features of Macrofungi and Plants (page 342)

- 1. Macrofungi features:** Most are decomposers (saprophytic). Vary from single celled to large multicellular molds. Rigid cell walls of chitin. Hyphae present in filamentous molds. Spread by spores.

Lichens are a symbiosis between a phototroph (usually an alga) and a fungus.

Note: Mosses, liverworts, ferns, gymnosperms, and angiosperms are all plants and are autotrophic.

- 2. Moss and liverwort features:** Lack vascular tissues. Small and restricted to damp environments. Root-like rhizoids anchor plant in ground. In mosses, the plant body is leaf-like. In liverworts it may be leaf-like or a flattened thallus.
- 3. Fern features:** True vascular plants. Plant body consists of underground stem or rhizome which bears the leaves (fronds) and roots. Conspicuous spore cases on the undersides of fronds. Clearly defined alternation of generations between large, leafy sporophyte and small, heart-shaped gametophyte.
- 4. Gymnosperm features:** True vascular plants. Most are woody plants bearing seeds in cones. Other have naked seeds. Many are evergreen. Male cones shed pollen. Seeds are contained in the female cones.

Note: General angiosperm features: Vascular plants, producing flowers, fruits, and seeds.

- 5. Monocot angiosperm features:** Herbaceous (non-woody). Flower parts in multiples of three. Leaves narrow with parallel veins. Seeds have a single cotyledon.
- 6. Dicot angiosperm features:** Herbaceous or woody. Flower parts in multiples of four or five. Leaves often broader than in monocots with netted (branching) vein pattern. Seeds have two cotyledons.

Features of Animal Taxa (page 343)

Visible identifying features only including:

- 1. Cnidarian features:** Body radially symmetrical. Medusoid (jellyfish) or hydroid (Hydra) body shape. Body wall of two layers separated by jellylike mesoglea. Tentacles with stinging cells for prey capture.
- 2. Annelid features:** Body more or less cylindrical and obviously segmented. Move by peristalsis, short appendages, or whole body undulations (leeches).

General arthropod features: Insects, crustaceans, arachnids, and myriapods are all arthropods and share some common features as follows; an exoskeleton of chitin and protein that is shed periodically to allow growth. Paired jointed appendages (legs, mouthparts). Segmented body but with a tendency for loss, fusion or specialization of segments to various degrees in different groups.

- 3. Insect features:** Adult body composed of head, thorax and abdomen. Most adults have one or two pairs of wings (some have secondary loss of the wings). Juvenile forms may be maggot-like or similar to the adult. Three pairs of jointed legs off the thorax. All other appendages (including mouthparts) also paired and jointed. Compound eyes.
- 4. Crustacean features:** Most are marine. Exoskeleton often impregnated with mineral salts (calcium carbonate and calcium phosphate). Body covered, at least partly, by a hard carapace. Paired, jointed appendages (often specialized to perform different functions). Two pairs of antennae. Gills often present. Compound or simple eyes. Diverse group; many are highly specialized.

5. **Arachnid features:** Exoskeleton of chitin and protein (as in other arthropods). Body divided into cephalothorax (combined head and thorax) and unsegmented abdomen. No antennae. First two pairs of appendages are feeding structures called chelicerae (fangs) and pedipalps. Terrestrial. Four pairs of walking legs. Many are poisonous with stings or venom sacs. Simple eyes. Spiders produce silk.
6. **Myriopod features:** Terrestrial. Elongated body with many obvious segments bearing paired legs. Head has a pair of antennae and two or three pairs of mouthparts. Centipedes have poison claws behind the mouthparts. Simple eyes. Most millipedes are slow moving, whereas many centipedes are rapid runners.
7. **Mollusc features:** Unsegmented. Muscular foot for movement. Upper body forms a fleshy mantle which may secrete a protective calcium carbonate shell. Scraping feeding organ or radula. Otherwise the group is very diverse. Aquatic and terrestrial. Commonly recognized groups are the shelled gastropod snails and sea slugs and the bivalved mollusks (mussels etc.). The cephalopods (squids and octopus) are highly specialized: the foot is divided into tentacles and they have highly developed eyes.
8. **Echinoderm features:** Marine. Adults radially symmetrical. Body wall rigid (with a skeleton of tiny calcareous plates). Spines are common. Some (sea lilies) are attached, most are mobile. Fluid filled tube feet used for locomotion. In most, mouth points down.

Note: As follows - fish, amphibians, reptiles, birds and mammals are all vertebrates (internal bony skeleton). Paired nostrils and eyes.

9. **Fish features:** Aquatic, ectotherms. Skin slippery with mucus and covered with scales. Gills. Usually well developed fins and tail. Body shape varies depending on swimming mode. Obvious lateral line organ along body. Lack eyelids and tongue.
10. **Amphibian features:** Adaptations for both aquatic and terrestrial life. Ectothermic. Smooth (non-scaly) skin covered with mucous glands. Moveable eyelids. Tympanic membrane for ear present in frogs. Muscular, protusible tongue. Legs and feet (may be webbed) adapted both for swimming and for moving on land.
11. **Reptile features:** Largely terrestrial or semi-aquatic. Dry, thick skin with horny scales or plates. May have legs or be legless (snakes). Tympanic membrane often present. Most lay shelled eggs. Most have well developed eyes.
12. **Bird features:** Endotherms. Horny scales on feet, but feathers over most of the body. Beak, lacking teeth. Adapted for flight (wings, light skeleton) although some are secondarily flightless. Lay heavily shelled eggs.
13. **Mammal features:** Endotherms covered with hair or fur. Glandular skin. Young born live except monotremes which lay eggs. Mammary glands produce milk for young. Teeth often highly specialized. (Internal features: secondary palate and diaphragm.)

Classification System (page 345)

1. (a) 1. Kingdom
2. Phylum
- (b) 1. Animal
2. Chordata

3. Class
4. Order
5. Family (given)
6. Genus
7. Species
3. Mammalia
4. Primates
5. Hominidae
6. *Homo*
7. *sapiens*

2. A two part naming system where the first word (capitalized and italicized) denotes the genus and the second word (lower case and italicized) denotes the species. Sometimes a third word (also lower case and italicized) denotes a subspecies.
3. (a) and (b) in any order:
Avoid confusion over the use of common names for organisms, provide a unique name for each type of organism, attempt to determine/define the evolutionary relationship of organisms (phylogeny).
4. Any one of the following:
DNA profiling/sequencing: Where the unique genetic makeup of an individual is revealed and used for comparisons with related organisms.
DNA hybridization: Where the percentage DNA similarity between organisms is compared.
Amino acid sequencing: Where the number of amino acid differences between organisms are compared.
Immunological distance: Indirectly estimate the degree of similarity of proteins in different species.
5. (a) **Monotreme:** Egg laying with little internal development before laying, most development takes place in the egg
(b) **Marsupial:** Birth takes place after limited internal development. Most development occurs after 'fetus' moves to the pouch and attaches to the nipple.
(c) **Placental:** Long period of internal development, sustained by placenta. Birth takes place at highly developed stage.

Classification Keys (page 347)

1. The case (presence or absence and specific features of the case).
2. A *Oxyethira* E *Hydrobiosis*
B *Hudsonema* F *Helicopsyche*
C *Olinga* G *Triplectides*
D *Aoteapsyche*
3. **Insect order (Common name)**
(a) Plecoptera (stoneflies)
(b) Hemiptera (bugs)
(c) Coleoptera (beetles)
(d) Odonata (dragonflies and damselflies)
(e) Lepidoptera (moths and butterflies)
(f) Trichoptera (caddisflies)
(g) Ephemeroptera (mayflies)
(h) Megaloptera (dobsonflies)
(i) Diptera (true flies)

Keying Out Plant Species (page 349)

1. (a) Silver maple, *Acer saccharinum*
(b) Japanese maple, *Acer palmatum*
(c) Red maple, *Acer rubrum*
(d) Sugar maple, *Acer saccharum*
(e) Black maple, *Acer nigrum*
2. Any one of: The size of the tree or shrub, the colour of

the bark and flowers, the shape of the winter buds and winged fruit.

- Before a plant can be classified to species level a number of different features must be considered. One feature is often not sufficient to accurately distinguish between closely related species within the same genus.
- The key must be for the genus of plant that the unidentified species belongs to as well as include the species of unidentified plant.

Designing Your Field Study (page 351)

- An appropriately sized sampling unit enables you to obtain sufficient data to test your predictions, but not so much that its analysis is too time consuming.
 - Recognizing assumptions is critical to asking the appropriate questions in a study. It also allows you to recognize possible reasons for findings that do not support your predictions. **Note:** For even the simplest of studies, some background information is important. Making some intelligent assumptions based on present knowledge allows you to focus on the questions that you really want to answer.
 - Appropriate consideration of the environment helps to ensure that the environment is not significantly changed by your sampling activities.
 - Returning organisms to the same place after removal ensures that the usual distribution of organisms in the environment is preserved.
 - The sampling area within which sites are located must be large enough to incorporate sites representing the variations in habitat seen within the region for which predictions are being made (e.g. coniferous forest).
- To test quadrat size it would be necessary to sample using a series of quadrats of increasing size. When only one species is involved, it is simplest to record the number of individuals for a range of different quadrat sizes. This gives some idea of variation in numbers and allows you to choose a quadrat size where the number recorded meets the needs of the data analysis (usually 10-100 individuals). **Note:** For community studies involving more than one species, the cumulative number of species recorded after each successive increase in quadrat size could be plotted (i.e. number of species vs quadrat size). Optimum quadrat size occurs when the number of species recorded stops increasing. A smaller size may be acceptable if you are prepared to record only dominant species. This always carries a risk that differences between areas may be missed.

Checklist to be completed by the student.

Monitoring Physical Factors (page 353)

- Severity of wave action:**
Exposed coastline: Severe wave action (high impact).
Estuarine mudflat: Very little wave action (tidal only).
Light intensity and quality:
Exposed coastline: High light intensity, full spectral range except for organisms either submerged or beneath dense seaweed (lower light intensity and less long wavelength light).
Estuarine mudflat: For the mudflat surface: full intensity and spectral quality.

Salinity/conductivity:

Exposed coastline: Near full salinity (3.3-3.7% dissolved salts) low on the shore. May be lower higher on shore (further from the sea).

Estuarine mudflat: Less saline than rocky shore because of the influence of freshwater input. (Also tends to vary depending on sampling position in the estuary and tidal input, fluctuating from nearly freshwater to almost full strength seawater).

Diurnal temperature change:

Exposed coastline: Very little diurnal fluctuation of water temperature near the sea. Greater fluctuation in the pools of the upper shore.

Estuarine mudflat: Wider fluctuations in water temperature depending on tidal input and water depth.

Substrate/sediment type:

Exposed coastline: Hard substrate (high exposure) with no fine particulates.

Estuarine mudflat: Soft substrate, fine particulates.

Oxygen concentration:

Exposed coastline: High, relatively uniform, oxygen concentrations near the sea. Lower and more variable in the pools of the upper shore.

Estuarine mudflat: Wider fluctuations in oxygen concentration depending on the water temperature, and tidal and riverine inputs.

Exposure time to air (tide out):

Exposed coastline: From very little exposure near the sea to longer periods of exposure higher on the shore.

Estuarine mudflat: Long periods of exposure.

- As the vertical distance up the trunk increases, light intensity and temperature increase and humidity declines. With these changes in physical conditions there is consequent change in the vegetation from a diverse community of shade and moisture adapted moss species, to a community comprising just one species of (hardier) tree moss and various species of lichens, i.e. species more tolerant of the microclimate of lower humidity and higher light and temperature.

Indirect Sampling (page 355)

- (a) and (b) any of: Calls, tracks, markings on vegetation.
- The EPA would be able to gather information on the distribution of various frog species, population size (from the number of frogs heard calling), and their habitat quality (from the location, habitat assessment, water quality, and weather data).
- Other indirect methods of population sampling include (any one of the following): Number of fecal pellets, frequency of calls, pelt records, number of artifacts (e.g. burrows, nests, pupal cases), gut contents of predators, questionnaires for hunters/recreational fishers, feeding capacity (bait taken) before and after poisoning, frequency of carcasses found on the road. **Advantages** include the estimate of populations of organisms that are normally elusive, easily disturbed or widely dispersed. **Disadvantages** of using indirect sampling methods are that the measures of abundance are less reliable than direct sampling methods.

Sampling Populations (page 356)

1. We **sample** populations in order to gain information about their abundance and composition. Sampling is necessary because, in most cases, populations are too large to examine in total.
2. (a) Plant percentage cover: Random or systematic quadrat sampling.
(b) Plankton density/age structure: Random or systematic point sampling (using a vertical haul net or plankton trap).
(c) Altitudinal change in community composition. **Note:** If time for sampling and analysis is constrained, a line transect with point sampling from low to high altitude. If time for sampling and analysis is less constrained, a belt transect using quadrats at regular intervals provides the most information.

Quadrat Sampling (page 357)

1. Mean number of centipedes captured per quadrat:
Total number centipedes ÷ total number quadrats
= 30 individuals ÷ 37 quadrats
= **0.811 centipedes per quadrat**
2. Number per quadrat ÷ area of each quadrat
 $0.811 \div 0.08 = 10.1$ centipedes per m^2
3. Clumped or random distribution.
4. Presence of suitable microhabitats for cover (e.g. logs, stones, leaf litter) may be scattered.

Quadrat-Based Estimates (page 358)

1. Species abundance in plant communities can be determined by using quadrats and transects, and abundance scales are often appropriate. Methods for sampling animal communities are more diverse, and density is a more common measure of abundance.
2. **Size:** Quadrat must be large enough to be representative and small enough to minimize sampling effort.
3. **Habitat heterogeneity:** Diverse habitats require more samples to be representative because they are not homogeneous.
4. (a) and (b) any two of:
 - The values assigned to species on the abundance scale are subjective and may not be consistent between users.
 - An abundance scale may miss rarer species and overestimate conspicuous ones.
 - The scale may be inappropriate for use in some habitats.
 - The semi-quantitative values assigned to the abundance categories cover a range so results will lack precision.

Sampling a Leaf Litter Population (page 359)

The actual results for this practical are not particularly important. What is valuable is learning the limitations of this method **before** being asked to carry it out in a field situation. The results will vary, depending upon the group's agreed criteria for including organisms in a quadrat.

6. Typical results for samples used are:

	Direct count	A	B	C	D
Woodlouse:	89	9.5	5	13	14.5
Centipede:	3	0	0	1	1
False scorpion:	3	1	0	1	0
Springtail:	6	0	3	0	0
Leaf:	168	29	20.5	24.5	26.5

Class results will vary depending on counting criteria.

7. Typical results for calculated density are:

	Direct count	A	B	C	D
Woodlouse:	2747	1759	926	2407	2685
Centipede:	93	0	0	185	185
False scorpion:	93	185	0	185	0
Springtail:	185	0	556	0	0
Leaf:	5185	5370	3796	4537	4907

Area of 6 quadrats = $(0.03 \times 0.03) \times 6 = 0.0054 m^2$

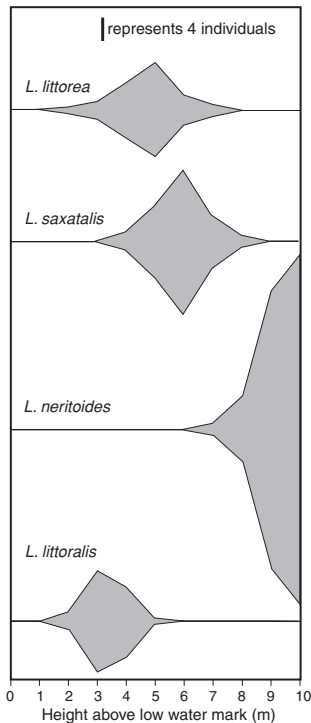
Area of total sample area = $0.18 \times 0.18 = 0.0324 m^2$

8. (a) **Problems** with sampling moving organisms: Once the quadrats have been laid, the animals moving from one quadrat to another risk being counted twice. **Solutions:** The quadrat could involve the placement of physical barriers between each quadrat (what about the invertebrates directly underneath). Possibility of exposing the entire area and photographing it for later analysis.
(b) Exemplar data given in the tables above. Students should be aware of the significance of extrapolating data from a small sample. The inclusion or exclusion of single individuals may have a large effect on the calculated density, particularly where species occur in low numbers.

Extension: Groups could combine their data to see if they get a more representative sample.

Transect Sampling (page 361)

1. (a) With transects of any length (10 m or more), sampling (and sample analysis) using this method is very time consuming and labor intensive.
(b) Line transects, although quicker than belt transects, may not be representative of the community. There may be many species which are present but which do not touch the line and are not recorded.
(c) Belt transects use a wider strip along the study area and there is much less chance that a species will not be recorded.
(d) It is not appropriate to use transects in situations involving highly mobile organisms.
2. To test whether or not the transect sampling interval was sufficient to accurately sample the community, the sampling interval could be decreased (e.g. from a sampling interval of every 1.5 m to an interval of every 0.25 m). If no more species are detected and the trends along the transect remain the same, then the sampling interval was adequate.
3. Distribution of *Littorina* species along a rocky shore. Note that this figure has been laterally compressed to fit the format of this booklet:



Mark and Recapture Sampling (page 363)

- Results will vary from group to group for this practical. The actual results are not important, but it should serve as a useful vehicle for discussion of such things as sample size, variation in results between groups, and whether the method is a reliable way to estimate the size of a larger unknown group. Discussion could center around what factors could be altered to make it a more reliable method (e.g. larger sample size, degree of mixing, increasing number of samples taken).
- Trout in Norwegian lake:**

Size of 1st sample:	109
Size of 2nd sample:	177
No. marked in 2nd sample:	57
Estimated total population:	$109 \times 177 / 57 = 338.5$
- (a) Some marked animals may die.
(b) Not enough time for thorough mixing of marked and unmarked animals.
- (a) and (b) in any order (any two of):
 - Marking does not affect their survival.
 - Marked & unmarked animals are captured randomly.
 - Marks are not lost.
 - The animals are not territorial (must mix back into the population after release).
- (a) Any animal that cannot move or is highly territorial (e.g. barnacle, tube worm, many mammals).
(b) Unable to mix with unmarked portion of the

population. Recapture at the same location would simply sample the same animals again.

- (a)-(c) in any order:
 - Banding: leg bands of different color on birds.
 - Tags: crayfish shell, fish skin, mammal ears.
 - Paint/dye used to paint markings in shell/fur.
- The scientists obtain information on fish growth to establish the relationship between age and growth. This will help manage the population to prevent overfishing. Tracking also helps to map breeding grounds and migrations so that fish can be protected at critical times in their life histories. In addition to these data, researchers will find out more about the general biology of the cod (e.g. data on feeding), which will help in the long term management and recovery of the fish stock.

Sampling Animal Populations (page 365)

- (b) **Beating tray:** Provides a qualitative sample of the organisms in a certain height of vegetation.
(c) **Longworth trap:** Provides a qualitative assessment of small mammal population in the area (may be biased because of trap avoidance in some species).
(d) **Plankton net:** Provides a quantitative sample of lake or pond zooplankton. (Volume filtered can be calculated according to the length and diameter of the net, and the lake depth). Species and/or life stages caught are dependent on mesh size.
(e) **Sweep net:** Provides a qualitative sample of the organisms in lower vegetation.
(f) **Water sampler:** Provides a quantitative sample of water at a certain, measured, depth in a lake or pond. Used for chemical, or sometimes phytoplankton, analyses. (Not a suitable sampling method for zooplankton which can evade capture).
(g) **Pooter:** Provides a means of capturing small invertebrates from leaf litter (can be quantitative if animals are removed from a known area of litter).
(h) **Tullgren funnel:** Provides a means of capturing small invertebrates from soil or leaf litter. It is biased towards those species showing light and/or heat avoidance behavior (can be quantitative if animals are removed from a known area/volume of litter/soil).
(i) **Pitfall trap:** Provides a qualitative sample of ground dwelling invertebrates.
- Pitfall traps rely on being placed in an area where the organisms are active. The traps take no account of clumped distributions or microhabitat preferences, overestimating densities in some areas and underestimating them in others.
- (a) **A large mesh size may fail to capture** some smaller plankton species or life stages (e.g. rotifers and copepod nauplii), which would pass through a large mesh. A very **fine mesh is apt to clog**, especially in highly productive waters. Clogging reduces filtering efficiency so that much of the sampled volume is pushed out of the net instead of passing through it.
(b) Mesh size should be fine enough to capture most or all of the species in which you are interested and it should be coarse enough to filter efficiently.

Human Impact on Resources (page 369)

- (a) 7.7 billion (b) 9.37 billion (c) 11.2 billion
- (a) Africa
(b) Poor education on family planning. Entrenched cultural practices (large families are desirable).
- River deltas are attractive areas for human settlement because they are highly fertile regions, rich in nutrients and adjacent to an abundant supply of water making it an ideal region for establishing agricultural activities. In addition, the deltas provide an abundance of food in the form of fish and shell fish.
Human population of deltas have impacted negatively in the following ways;
 - Increased erosion due to agriculture and deforestation results in sedimentation of the river system.
 - Damming and other river control measures prevent annual flooding which the delta needs to replenish soil nutrients. Salts also build up in the soils and cause crops to fail.
 - Fertilizer application is increased which results in pollution of the water way.
 - Food supplies from the waterways may decrease or become depleted if fishery controls are not in place. Pollution of water may also affect fish stock.

- Student's discussion may include any of the following:

WATER

- No plant or animal can survive without water and there are no substitutes for its use.
- Water poor regions such as the Middle East and North Africa rely on the Tigris Euphrates and Nile river systems respectively for their water supply. Damming of the river system or increased use by one country greatly affects the availability of the users downstream. This may create political tensions which could result in 'water wars'.
- Without sufficient water crops and other agricultural activities will fail and will result in food shortages. The number of countries suffering famines will increase, and food prices in general will increase putting economic pressure on developing countries and other low socio-economic regions.
- Many countries rely on electricity generation from hydro electricity production. A restriction in electricity generation could cause blackouts, resulting in reduced manufacturing capacity and potentially putting lives in danger if medical facilities do not have sufficient back up generation methods.
- Water shortages will impact on the ecosystems based in or around water sources, and result in loss of biodiversity

OIL

- An energy shortage will develop, which may result in rolling blackouts to control supply. Basic needs such as cooking and heating become more expensive. Living standards would be lowered.
- The cost of transportation fuel will increase and will restrict travel (including international travel) and impact on tourism industries.
- Manufacturing costs will increase as most of

industry is directly or indirectly dependent upon oil for manufacturing or transportation of their goods.

- Diminishing oil supplies could result in wars to gain better access to the remaining supplies.
- The world's economy may fall into a recession and inflation may increase.

Pollution (page 371)

- (a) **Accelerated nutrient enrichment and eutrophication:** Source: Primarily nitrogen and phosphorus run off from agricultural land directly into waterways or into groundwater. Effects: Excessive growth and decay of algae and plants, accompanied by oxygen depletion. Certain weedy species are favoured over more desirable macrophytes. Water quality is severely reduced.
 - (b) **Acid deposition:** Source: Sulfur dioxide and nitrogen dioxide from industrial emissions. These mix with water vapor to form acidic precipitation. Effect: Defoliation and stunting of vegetation, damage to buildings, acidification of soils and water bodies, leading to change in the usual biota towards low-pH tolerant species.
 - (c) **Smog and ozone:** Source: A reaction between sunlight and the hydrocarbons and nitrous oxides from vehicle exhausts. Effect: Reduces visibility and causes respiratory and other health problems. It also stresses plants and contributes to contraction of vegetated areas.
 - (d) **Radioactive wastes:** Source: Mining and processing of radioactive metals, leakage from inadequately stored nuclear waste, accidents at nuclear facilities. Effect: DNA damage and associated cancers and developmental deformities in a wide range of organisms (especially vertebrates). Persistence in the environment and accumulation in food chains (e.g. in milk).
 - (e) **Heavy metals:** Source: Primarily run off from open caste mining operations. Effect: Damages (and toxic to) metabolic systems by inactivating enzymes, e.g. respiratory enzymes. Slow to eliminate from the body.
- Non-point sources (NPS) of pollution are more difficult to identify and control because, unlike pollution from industrial and sewage treatment plants or power plants, they come from many diffuse sources, such as through land runoff.
 - Student's own discussion. Responses will be specific to their own home environment. Discussion could include reference to sources of the pollutants in the seven groups described in the diagram.
 - Student's own discussion. Responses will be specific to their own region.

Monitoring Change in an Ecosystem (page 373)

- Each of these water quality measurements must be made in the flowing water as these physical factors may immediately change if a sample is removed for later analysis (e.g. water sample will change temperature in the container, oxygen may be gained or lost, suspended matter may settle to the bottom thereby changing clarity).

2. Many land-based activities result in intentional or accidental discharges into waterways. Surface runoff during rain washes chemicals, silt, and organic matter into the natural drainage systems to rivers and lakes.
3. Species diversity index used in (any of):
 - Comparisons of similar ecosystems which have been subjected to (beneficial or detrimental) human influence (e.g. restoration or pollution).
 - Assessment of the same ecosystem before and after some event (fire, flood, pollution, environmental restoration).
 - Assessment of the same ecosystem along some environmental gradient (e.g. distance from a point source of pollution).
 - Assessment of the biodiversity value of an area for the purposes of management or preservation (tends to be a political lobbying point).
4. (a) $DI = 37 \times 36 \div ((7 \times 6) + (10 \times 9) + (11 \times 10) + (2 \times 1) + (4 \times 3) + (3 \times 2))$
 $= 1332 \div 262 = 5.08$
 (b) Without any frame of reference (e.g. for a known high or low diversity system), no reasonable comment can be made about the diversity of this ecosystem. Herein lies the problem with an index that has no theoretical upper boundary.
5. Certain species, called **indicator species**, are indicative of the health of an ecosystem and can be used to detect pollution in a stream. The diversity index, based on the diversity of macroinvertebrates found in a stream community, will be low in a stream that is polluted, even though abundance may be high.
- Positive feedback loops are inherent in all these changes as multiple processes accelerate the loss of ice.
3. Increased levels of carbon dioxide, methane, and nitrous oxides act as additional blankets around the Earth, allowing the sun's energy to reach the Earth's surface, but preventing the heat escaping. This means that the Earth slowly heats up. **Note:** The atmospheric concentrations of these gases have increased dramatically above pre-industrial levels since 1750. These levels are considerably higher than at any time during the last 650,000 years (the period for which reliable data has been extracted from ice cores) and are correlated with a rise in global temperature and documented sea level rises. While correlation does not mean cause and effect, the majority of climate scientists accept the theory that the increase in anthropogenic greenhouse gas emissions is causing the rise in the Earth's temperature.
4. Any one of:
 - Most national governments have signed and ratified the Kyoto Protocol aimed at combating greenhouse gas emissions.
 - Measures are in place to reduce or reverse future warming or to adapt to its expected consequences (mitigation or adaptation). Examples include reducing dependence on fossil fuels and long term planning to prepare for sea level rise and more severe weather events etc.)
 - Carbon credit schemes provide a tradable permit scheme to create a market for reducing greenhouse emissions by giving a monetary value to the cost of polluting the air.

Global Warming (page 375)

1. (a) Carbon dioxide: 30.9% increase
 (b) Methane: 111.0% increase
 (c) Nitrous oxide: 11.6% increase
2. Consequences of global temperature rise on Arctic ecosystems (main points): Higher temperatures will result in:
 - Accelerated melting of the Greenland ice sheets.
 - Releases of terrestrial carbon from thawing permafrost regions.
 - Releases of methane from hydrates in coastal sediments.
 - Expansion in ocean volume. Additional water (previously locked up in glaciers) will add to this increase.
 - Arctic melt season begins earlier and ends later.
 - Many Arctic species (e.g. polar bears) are at risk, especially those that inhabit the low lying areas near the sea and those that rely on cold weather conditions. Glaciers and ice sheets provide floating oases for wildlife (e.g. for rest when moving between bergs) and disappearing habitat is already forcing species such as polar bears and seals to make longer, riskier swims.
 - Reductions in sea ice reduce habitat for marine zooplankton (e.g. amphipods) and shifts species assemblages of phytoplankton. Both of these consequences alter the dynamics and resilience of marine food chains.
 - Tundra ecosystems will also be adversely affected as permafrost loses depth and species from all trophic levels are lost or replaced.

Stratospheric Ozone Depletion (page 377)

1. Ultraviolet radiation is a powerful carcinogen causing an increase in the mutation of genes and generally interfering with genetic processes. Notable are increased rates of all types of skin cancers.
2. UV light causes the release of free chlorine from CFCs and this chlorine destroys the ozone. The ozone layer absorbs most of the incoming UV and prevents it from reaching Earth. With fewer ozone molecules to absorb the UV, its penetration through the stratosphere is much greater and more reaches the Earth's surface.
3. (a) Greatest geographical extent: September to early October (Southern hemisphere early spring).
 (b) Most depleted: Mid-October (1992)
 (c) Trend of ozone depletion: Generally a steady decline over the last two decades with the exception of 1989 when there was a brief increase to 1983 levels.
 (d) In September 1997 the concentration of ozone between altitudes 10 and 20 km increased. By October 1997, ozone levels had declined markedly (to approx. 0 mpa pp at 15-20 km) between these altitudes. (The ozone was severely depleted at these altitudes in October but not in September).
4. Development and implementation of new technologies required to reduce ozone depleting chemicals is costly. Furthermore, the technology is controlled by

the affluent Western economies. Poorer developing countries will find it difficult to spend large amounts of money on converting to alternative technologies. Recent studies have suggested that some of the proposed replacement chemicals may themselves cause damage to ozone.

Ecosystem Stability (page 379)

- High diversity systems have a greater number of biotic interactions operating to buffer them against change (the loss or decline of one component (species) is less likely to affect the entire ecosystem). With a large number of species involved, ecosystem processes, such as nutrient recycling, are more efficient and less inclined to disruption.
- Keystone species** are pivotal to some important ecosystem function such as production of biomass or nutrient recycling. Because their role is disproportionately large, their removal has a similarly disproportionate effect on ecosystem function.
- (a) Sea otter: One of the favourite delicacies of the otter is the large sea urchin, which in turn feeds on kelp. Without sea otters there would be no kelp forests. The diversity of the sea otter's diet of marine invertebrate herbivores and filter feeders reduces competition between benthic grazers and supports greater diversity in those species.
(b) Beaver: When beavers build dams innumerable species, many threatened or endangered, benefit. Beaver ponds produce food for fish and other animals as well as creating habitat. Beaver activity is closely tied to the regeneration of quaking aspens. Beavers eat the bark of this (their favourite) tree and, by harvesting the trees, release buds for sucker growth and stand replacement.
(c) Gray wolf: Wolves, as a keystone predator, are an integral component of the ecosystems to which they belong. The wide range of habitats in which they thrive reflects their adaptability as a species. Their diet includes elk, caribou, moose, deer and other large ungulates, as well as smaller prey. Wolves are sensitive to fluctuations in prey abundance, and the balance between wolves and their prey preserves the ecological balance between large herbivores and available forage.
(d) Quaking aspen: An aggressive pioneer species that frequently colonises burned ground. The success of quaking aspen is attributed to its extensive root system, which sends up suckers to produce clones of the parent tree. The open canopies of aspen groves allow a rich and diverse understorey of shrubs, forbs and grasses to feed and shelter a variety of wildlife. A large number of birds and browsing mammals are dependent on aspen stands for survival, especially through winter periods.
- Humans historically kill off top carnivores when they enter a natural ecosystem and this drastically affects biodiversity and leads to ecological imbalances. For example, **wolves** were nearly hunted out of existence in the USA and Europe prior to the twentieth century. Following eradication of wolves in Yellowstone National Park in the early 1900s, elk numbers increased markedly, destroying vegetation and driving beavers and other animals from the damaged habitats. The pivotal role of top predators was determined only after ecological research during the last century and, as a consequence, wolves were reintroduced to Yellowstone

and Idaho. The return of the wolves has resulted in a return of biodiversity as the ecological balance has been restored.

Another similar case is the depletion of **sea otter** populations as a result of the fur trade from the mid 1700s to 1911. Removal of the otters resulted in a population explosion of sea urchins (on which the otters preyed) and destruction of the local kelp forests on which a large variety of smaller animals depended. As the sea otter populations recover following reintroductions to the natural range, populations of abalone and sea urchins are predicted to decline, allowing a recovery of marine plant biomass.

Loss of Biodiversity (page 381)

- 1 Tropical Andes**
The richest and most diverse hotspot where it is home to 20 000 endemic plants and at least 1500 endemic non-fish vertebrates.
- 2 Sundaland**
Some of the largest islands in the world are found here in Southeast Asia. The second-richest hotspot in endemic plants, and well known for its mammalian fauna, which includes the orangutan.
- 3 Mediterranean basin**
The site of many ancient and modern civilisations, it is the archetype and largest of the five Mediterranean-climate hotspots (also see nos. 9, 12, 19 and 22). One of the hotspots most heavily affected by human activity, it has 13 000 endemic plants, and is home to a number of interesting vertebrates such as the Spanish ibex.
- 4 Madagascar and Indian Ocean islands**
Madagascar is a top conservation priority as this 'mini-continent' has undergone extensive deforestation. This hotspot is famous for reptiles such as chameleons and is home to all the world's lemur species.
- 5 Indo-Burma**
An area stretching from the eastern slopes of the Himalayas through Burma and Thailand to Indochina. This region hosts the world's highest freshwater turtle diversity (43 species), and a diverse array of mammals. Several new ungulate species, such as the saola and giant muntjac, were recently discovered here.
- 6 Caribbean**
One of the highest concentrations of species per unit area on Earth. Reptiles are particularly diverse (497 species are found here), 80 percent of which are found nowhere else. Non-fish vertebrates number 1518.
- 7 Atlantic Forest region**
Once covering an area nearly three times the size of California, the Atlantic Forest has been reduced to about 7% of its original extent. It is most famous for 25 different kinds of primates, 20 of which are endemic. Among its best-known 'flagship species' are the critically endangered muriquis and lion tamarins.
- 8 Philippines**
The most devastated of the hotspots, the forest cover has been reduced to 3% of its original extent. The Philippines is especially rich in endemic mammals and birds, such as the Philippine eagle.
- 9 Cape Floristic Province**
This Mediterranean-type hotspot in southern Africa covers an area roughly the size of Ireland, and is

now approximately 20% of its original extent. It is home to 8200 plant species, more than 5500 of which are endemic.

10 Mesoamerica

Forming a land bridge between two American continents, this hotspot features species representative of North and South America as well as its own unique biota. The spider and howler monkeys, Baird's tapir and unusual horned guan are 'flagship species'.

11 Brazilian Cerrado

A vast area of savanna and dry forest, the Cerrado is Brazil's new agricultural frontier and has been greatly altered by human activity in the past few decades. Home to 4400 endemic plants and several well-known mammal species, including the giant anteater, Brazilian tapir, and maned wolf.

12 Southwest Australia

A Mediterranean-type system, this hotspot is rich in endemic plants, reptiles, and marsupials including the numbat, the honey possum and quokka. It is also home to some of the world's tallest trees, e.g. the giant eucalyptus.

13 Mountains of South-Central China

An area of extreme topography, these mountains are home to several of the world's best-known mammals, including the giant panda, the red panda, and the golden monkey. This hotspot is largely unexplored and may hold many undiscovered species.

14 Polynesia/Micronesia

This hotspot comprises thousands of tiny islands scattered over the vast Pacific, from Fiji and Hawaii to Easter Island and is noteworthy for its land snails, birds, and reptiles. Hawaii has suffered some of the most severe extinctions in modern history, due in part to the introduction of non-native plant and animal species.

15 New Caledonia

One of the smallest hotspots yet it has the largest concentration of unique plants with five plant families found nowhere else on Earth. This hotspot also features many endemic birds, such as the kagu, a long-legged, flightless forest dweller representing an entire bird family.

16 Choco-Darien Western Ecuador

Some of the world's wettest rain forests are found here, and amphibians, plants and birds are particularly abundant. It has one of the highest levels of endemism of any hotspot with 210 endemic amphibian species of the 350 species found here.

17 Guinean Forests of West Africa (in error, this hotspot was not numbered on the map). With the highest mammalian diversity of any hotspot, these forests are home to the rare pygmy hippopotamus and many other striking species, including the western chimpanzee, Diana monkey and several forest duikers. The numbers of these endemic mammals have been severely reduced by large-scale logging and hunting.

18 Western Ghats/Sri Lanka

The Western Ghats mountain chain and adjacent island of Sri Lanka harbour high concentrations of endemic reptiles; of 259 reptile species, 161 are found nowhere else on Earth. This hotspot is also home to a number of 'flagship species', including the lion-tailed macaque.

19 California Floristic Province

Extending along the coast of California and into Oregon and northwestern Baja California, Mexico, this is one of five hotspots featuring a Mediterranean-type climate of hot, dry summers and cool, wet winters. It is especially rich in plants, with more than 4000 plant species, almost half of which are endemic.

20 Succulent Karoo

The only arid hotspot, the Succulent Karoo of southern Africa is renowned for unique succulent plants, as well as lizards and tortoises. In Namaqualand, in the southern part of this hotspot, a seasonal burst of bloom in September attracts many tourists.

21 New Zealand

This hotspot claims a number of world-famous endemic bird species, including kiwi (a nocturnal, flightless bird), takahe (a diurnal, flightless bird), and the critically endangered kakapo (a large, flightless parrot).

22 Central Chile

This hotspot features an arid region as well as a more typical Mediterranean-type zone. Best known for its incredible variety of plant species but also features unusual fauna, including one of the largest birds in the Americas, the Andean condor.

23 Caucasus

Situated between the Black Sea and the Caspian Sea, Caucasus habitats range from temperate forests to grasslands. A diversity of plants have been recorded here with some 6300 species, more than 1600 of which are endemic.

24 Wallacea

Named for the 19th century naturalist Alfred Russel Wallace, this hotspot comprises the large Indonesian island of Sulawesi, the Moluccas and many smaller islands. The area is particularly rich in endemic mammals and birds.

25 Eastern Arc Mountains/ Coastal Forests of Tanzania and Kenya

A chain of upland and coastal forests, this hotspot claims one of the densest concentrations of endemic plant and primate species in the world. It is home to African violets and 4000 other plant species, as well as the 1500 remaining Kirk's red colobus monkeys.

2. Student's own opinion as supported by an explanation. The major threats to biodiversity include: Population growth and resource consumption, over-hunting/ commercial exploitation, illegal trading, habitat conversion and sprawl, establishment of exotic and invasive species, environmental degradation/pollution, and global warming.

Tropical Deforestation (page 382)

- (a) They enhance removal of carbon dioxide from the atmosphere (anti-greenhouse).
(b) They maintain species diversity.
(c) They have, as-yet-undiscovered, potentially useful species for medicines etc.
- Tropical deforestation has three primary causes: logging, fires, and road-building (associated with clearance for agriculture). Logging and fires destroy forest. Intrusion of roads into pristine forested areas

allows the invasion of weed species, increases erosion, and prevents the reestablishment of forest species. Agriculture maintains cleared areas and prevents forest reestablishment. Continued agriculture on thin tropical soils precludes the easy reestablishment of forest once the agricultural land has been abandoned.

Endangered Species (page 383)

- Students should give an answer appropriate to their species choice. Typically, recent extinctions are associated with hunting (e.g. dodo, passenger pigeon), severe habitat loss or fragmentation, introduction of alien species as competitors and/or predators (e.g. Stephen's Island wren).
- (a) and (b) in any order:
 - Preserving biodiversity on Earth is ultimately of benefit to humans. Preserving biodiversity ensures the continued existence of species/foods/medicines/ natural materials that could be of future use.
 - Other species have a right to exist alongside humans. As the main instigators of change on the planet, humans have a moral obligation to act as guardians of biodiversity for future generations.
- (a) and (b) Students should give an answer appropriate to their own country or local region. Link into CITES and WWF through Bio links for information. Typical reasons for decline (b) include: human pressure and habitat loss, degradation, or fragmentation, pressure from introduced predators or competitors, hunting/ trade, introduction and spread of diseases as a result of contact with alien species.

Conservation of African Elephants (page 384)

- In 1989, the African elephant was placed in Appendix 1 of CITES, which imposed a ban on trade in living or dead material from elephants.
- (a) A limited legal trade in ivory has resulted from a policy of management and quota operation. Removal of the ban on ivory has allowed the rural communities of these countries to earn money from the controlled exploitation of their wildlife. (Advocates of this claim that it has dramatically increased the amount of land given over to wildlife, as the returns from wildlife exploitation have exceeded those from cattle).
- (b) Any two of:
 - Quota systems can be abused (and have been in the past, with illegal hunting continuing).
 - As returns from ivory increase there will also be pressure to extend the quota above what individual elephant populations can sustain.
 - As ivory is traded, there will be pressure to illegally bring in ivory (for trade) poached from vulnerable populations outside quota countries.

Nature Reserves (page 385)

- (a) Captive breeding of animals: Used to boost the numbers of an endangered species so that reintroductions into the wild become feasible. By augmenting wild populations with captive bred individuals, it is hoped that wild populations can return to viable levels. Captive breeding programs are carefully managed to ensure genetic diversity is

maintained or bettered.

- (b) Botanic gardens and gene banks provide banks of genetic diversity which can be used to improve the viability of inbred lines. Gene banks are particularly important with respect to crop plants, where rarer low-yielding wild types are no longer cropped, and retaining a bank of "wild genes" guards against loss of genetic diversity.
- In situ* conservation measures argue for a whole-ecosystem management approach to saving species. If whole-ecosystem restoration is successful it offers a good chance of species recovery, even for critically endangered species. It has the advantages of less disturbance to the species involved, it by-passes the need for captive breeding (which is unsuccessful for some species), and it offers a greater chance of long term success because habitat restoration goes hand in hand with species management.
- Student's own example as supported by a brief discussion.
- Student's own discussion based on their chosen example. Protected areas usually have high conservation value because of the species found there (native, endemics etc), the esthetic values of the area, or the representative ecosystem type (for example, a remnant area of pristine habitat).

Pest Control (page 387)

- (a) **Toxicity:** A measure of how poisonous a chemical is to target and non-target species.
 (b) **Specificity:** A measure of how selective the pesticide is in targeting a specific pest.
 (c) **Biodegradable:** Can be broken down by normal biological mechanisms.
 (d) **Bioaccumulation:** The accumulation of a pesticide (increasing concentration) as it is passed from one trophic level to the next. Bioaccumulation occurs because persistent pesticides are retained in body.
 (e) **Contact chemical:** A chemical that is effective when it comes into contact with surface tissue.
 (f) **Systemic chemical:** A chemical that must enter the circulation of the organism to be effective.
- (a) 1000 times (given) (c) $2 \div 1.2 = 1.7$ times
 (b) $1.2 \div 0.05 = 24$ times (d) $76 \div 2 = 38$ times
- Many target species adapt (in the evolutionary sense) to prolonged insecticide use by developing resistance. This means the insecticides become increasingly less effective against their targets and long term control fails as the resistance spreads through the population.
- Top consumers are most at risk because they eat a large number of prey items from lower trophic levels (therefore larger volumes of the chemical).
- Introduce an organism that will act as a parasite, predator, or pathogen of a pest species, thereby reducing its population numbers to a tolerable level. The pest is rarely completely eliminated, however.
- (a) Cane toads, instead of feeding on cane beetles, fed voraciously on native invertebrates and poisoned the native carnivores that tried to eat it. Cane toads spread quickly through Australia in the absence of any natural control agents.

- (b) It is now necessary for the efficacy and potential interactions of any proposed biocontrol agent to be thoroughly investigated through research and field trials. Their release must also be carefully controlled and their spread and effect on the target organism closely monitored.

The Impact of Alien Species (page 389)

- Student's own choice. One example is the introduction of the brushtail possum into New Zealand, where it has severely damaged forest ecosystems throughout the country, feeding on palatable tree species, preventing regeneration, and decimating native populations of invertebrates and birds.
- Student's own choice. One example is the biological control of the prickly pear cactus in Australia by the caterpillar of the moth *Cactoblastis cactorum*, which feeds directly on the cactus flesh. Control of the cactus by the caterpillar has been a spectacular success and now only scattered populations of the cactus occur.

Fisheries Management (page 390)

- Total landings and spawning stock biomass (a measure of the number of adults breeding) have been steadily declining since the early 1980s, and were indicating a decline (although not consistently) prior to that. As a consequence of declining spawning biomass, recruitment at age 1 also declined steadily during this period (with the exception of better years in 1984 and 1986). These data indicated unsustainable catches and decline of the stock below safe biological limits.
- Summary responses only given:
 - North Sea
 - Risk of stock collapse is high. Stock is outside safe biological limits; spawning stock supported by only a few age groups and is less than half the level considered safe. TAC now half of the TAC in 2000.
 - Important features of biology: size (age) at harvest, breeding range, age at first reproduction, growth rate, spawning behavior, effect of fishery on habitat.
 - Methods to assess sustainability include: surveys to estimate biomass (trawl and acoustic surveys, tagging), otolith examination to assess population age structure, assessment of stock recruitment (spawning assessment and survivorship).
 - Management options: size limits, deterring directed fishing, reducing by-catch of cod in other fisheries, restricted and closed seasons, reduced quota, closed areas (e.g. in breeding grounds), updating biological information on species spawning.

Ecological Impacts of Fishing (page 391)

- Over-exploitation** refers to harvesting a commercial fish species such that the population falls below its optimal size. Overexploited populations show a progressive decline in growth rate and thus in population size.
- By-catch**: The proportion of the catch that is discarded for economic, legal, or personal reasons.
- The **maximum sustainable yield** describes the largest amount of a naturally renewable resource (e.g. fish) that

can be regularly harvested without causing a decline in the stock. A catch over this level will be more than the population can sustain. Reproductive individuals will not be able to compensate (by breeding) for the loss of biomass and the stock will collapse.

- At about 5 or 6 years, being the point where stock numbers are still moderately high, total fish biomass is high, and individuals are of an intermediate size (relative to maximum achievable size). If the few, older (larger) individuals are taken, the population quickly becomes skewed towards younger fish with lower reproductive capacity.
 - 0-6 years
 - Longevity, age at which reproduction begins, mortality at different life stages.
- Discussion could include reference to any three of:
 - Placing a size/age limit on take.
 - Enforcing and regularly reviewing maximum sustainable yield so that fish stocks can replenish themselves and the catch never exceeds what can be supported by the population.
 - Limiting the number of licenses (to fish) issued.
 - Regulation of the fishing equipment used.
 - Limits on allowable by catch so that fishing vessels cannot keep fishing to remove only the large individuals while discarding smaller individuals of the same species.
 - For some species, supplementing the natural stocks with captive-bred fry.
- Any two advantages:
 - Can be used to enhance natural fish stocks.
 - Can be used to take the fishing pressure off natural stocks.
 - Undesirable bycatch could be usefully used to produce fish meal.
 - Any two disadvantages:
 - Producing fish meal to feed farmed fish uses more fish than is produced.
 - Fish farming can destroy natural fish habitat.
 - large effluent run-offs from fish farms can pollute.

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